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Nulls Placement of Circular Array Antenna Using Adaptive Differential Evolution Algorithm

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Abstract: The article describes the application of adaptive differential evolution (ADE) to optimize uniform circular array to produce radiation pattern with specified side lobe level (SLL) and null placement control. Two instances of null pattern synthesis are presented in this work. In the first problem ADE is used to synthesize multiple deep nulls at specific directions. In the second problem wide and deep nulls are generated at the angular sector of the arrival of broadband interferences. The optimization process is accomplished by perturbing the complex weights of the antenna element in the circular array. The simulation results show that it is possible to obtain an symmetric radiation pattern having deep and wide nulls on both sides of the main lobe with depth greater than -60dB. Proposed method is proved very efficient in solving the various problems of circular array antenna optimization.

Keywords: Adaptive Differential Evolution (ADE); Side lobe Level; Deep Nulls; Wide Nulls; Circular Array.

I. INTRODUCTION

Null pattern synthesis has an extensive use in communication since it is capable of suppressing interferences coming from specific directions. For broadband interferences, nulls are formed in the pattern at the wide angular sector in the direction of the arrival of the interferences.

A convenient way to solve the null pattern synthesis problems is the use of global stochastic optimization methods. Thus the metaheuristic approaches like genetic algorithm [1,2], ant colony optimization [3], particle swarm optimization (PSO) [4,5], differential evolution [6,7] and their derivatives are useful tools for these highly nonlinear optimization problems. The optimization techniques aim to find a set of excitations and antenna element positions that facilitate the radiation pattern to fulfill the stringent designing goals. The priori works related to null steering techniques is accomplished by controlling the complex weights [8,9], the amplitude only [10,11], the phase-only [12,13], and the position only of the array elements [14,15].

Literature [16,17] describes the synthesis of circular arrays using evolutionary algorithms.

In our paper we have presented two examples of null pattern synthesis. In the first example optimization algorithm is used to synthesize radiation pattern with desired side lobe level and multiple deep nulls at specific directions. In the second problem pattern is formed to place the deep nulls in the wide angular sector in the direction of the arrival of the broadband interferences. For both the cases side lobe level is kept at same value and the angular width of the main beam between the first nulls is not allowed to exceed a maximum limit. Algorithm calculates a symmetric excitation (amplitude and phase) distributions to place the deep and wide nulls on both sides of the main lobe with depth greater than -60dB. Interference suppression with complex weights offers greater degrees of freedom in the solution space. An improved variant of a popular metaheuristic algorithm called differential evolution (DE) is used for designing the proposed optimization problem. In the adaptive algorithm, parameter values like scale factor and cross over rate are automatically tuned according to the objective function values produced by the donor vector and target vector during the same run.

II. METHODOLOGY

We consider a circular array of N uniformly spaced radiating elements at a distance 0.5λ apart along the circle of radius r in the x-y plane, as shown in Fig. 1. The elements in the array are assumed to be isotropic so that the radiation pattern of the array can be described by its array factor. We need to vary the current excitation amplitude and phase to keep the peak SLL below a desired level where first null beam width is not allowed to exceed a fixed value and achieve a null control at desired directions.

The expression of the array factor for the circular array can be written as follows:

$$AF(\theta,\varphi)=\sum_{n=1}^{N} I_n e^{\psi_n}\{\exp(jkr[\sin\theta\cos(\phi-\phi_n)-\sin\theta_0\cos(\phi_0-\phi_n)])\} \quad (1)$$

where $k = \frac{2\pi}{\lambda}$, $r = \frac{Nd}{2\pi}$ and $\phi_n = \frac{2\pi n}{N}$, N is the number of array elements, $\theta \in [-\pi/2, \pi/2]$, $\phi \in [0, \pi]$, λ is the wavelength at the design frequency, d is the inter-element spacing, I_n is the excitation current amplitude and ψ_n is the excitation phase of each element.

Without loss of generality we may consider that peak of the radiation pattern is directed at $(\theta_0,\phi_0)=(0,0)$.

The problem is now to find the set of excitation distributions with the proposed adaptive DE that will generate the array pattern with desired SLL and nulls at specific directions. To achieve the optimization task fitness function is formed as follows:

$$Fit = (SLL_o - SLL_d)^2 + (\sum_{\theta_k} D_o(\theta_k) - D_d)^2 \quad (2)$$

SLL_0= Obtained maximum side lobe level (dB) in the entire theta domain except the main lobe and the angular regions considered for null placement. SLL_d= desired value of SLL in dB.

$$D_o(\theta_k)\big|_{dB} = \text{Value of } AF(\theta_k) \text{ in dB}$$

and θ_k is the direction of the nulls and D_d=desired null depth.

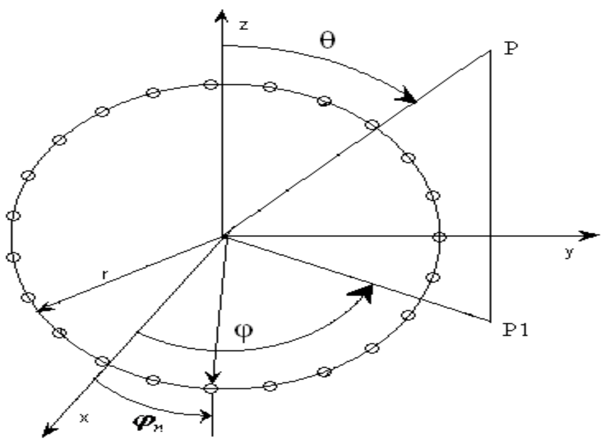

Figure.1. Uniform Circular Array of N isotropic elements

III. OVERVIEW OF ADAPTIVE DIFFERENTIAL EVOLUTION ALGORITHM

Differential evolution (DE) is a stochastic optimization problem that was introduced by Storn and Price [20-21]. Since inception DE is known as simple, robust and very fast global optimization technique over continuous spaces.

In each generation G, DE uses NP D-dimensional parameter vectors as a population as follows

$$\vec{X}_{i,G} = [x_{1,i,G}, x_{2,i,G}, x_{3,i,G}, \ldots, x_{D,i,G}] \quad (3)$$

For each parameter there may be a definite region where better search results are likely to be found. The initial population should cover the entire search space constrained by the specified upper and lower bound x_{max} and x_{min}.

Hence we may initialize the j-th component of the i-th vector as

$$x_{j,i,0} = x_{j,\min} + rand_{i,j}(0,1) \cdot (x_{j,\max} - x_{j,\min}) \quad (4)$$

where $rand_{i,j}(0,1)$ is a uniformly distributed random number lying between 0 and 1. This random initial population improves through mutation, crossover, and selection operations.

A. Mutation:

DE mutates and recombines the population to produce a population of NP trial vectors. In particular, differential mutation adds a scaled, randomly sampled, vector difference to a third vector.

$$\vec{V}_{i,G} = \vec{X}_{best,G} + F_i \cdot \left(\vec{X}_{r_1^i,G} - \vec{X}_{r_2^i,G} \right) \quad (5)$$

The indices r_1^i and r_2^i are mutually exclusive and randomly chosen integers. F_i is called scaling factor that is tuned automatically depending on the value of the cost function generated by each vector.

If the objective function value of any vector nears the objective function value attained by $\vec{X}_{best,G}$, F_i is estimated as follows.

$$F_i = 0.8 * \left(\frac{\Delta J_i}{\delta + \Delta J_i} \right) \quad (6)$$

where $\delta = 10^{-14} + \Delta J_i / 10$, $\Delta J_i = J(X_i) - J(X_{best})$ and $\Delta J_i < 2.4$

The expression results a lesser value of F_i causing lesser perturbation in the solution. So it will undergo a fine search within a small neighborhood of the suspected optima.

If $\Delta J_i > 2.4$ F_i is selected obeying the following relation.

$$F_i = 0.8 * \left(1 - e^{-\Delta J_i}\right) \quad (7)$$

Eq. (7) results a greater value of F_i that ultimately boosts the exploration ability of the algorithm within the specified search volume.

B. Crossover:

To increase the potential diversity of the population, crossover operation is introduced. In crossover the donor vector exchanges its components with the target vector $\vec{X}_{i,G}$ to obtain the trial vector $U_{i,G}$.

$$u_{j,i,G} = \begin{cases} v_{j,i,G} & \text{if } (rand_{i,j}(0,1) \le Cr_i \text{ or } j = j_{rand}) \\ x_{j,i,G} & \text{otherwise} \end{cases} \quad (8)$$

where $rand_{i,j}[0,\ 1]$ is a uniformly distributed random number and Cr_i is a constant called crossover rate. $j_{rand} \in [1,2,\ldots,D]$ is a randomly chosen index, which ensures that $\vec{U}_{i,G}$ gets at least one parameter from $V_{i,G}$ and does not become exact replica of the parent vector. The number of parameters inherited from the donor has a (nearly) binomial distribution.

$$Cr_i = \begin{cases} Cr_{const} & \text{if } J(\vec{V}_i) \le J(\vec{X}_{best}) \\ Cr_{\min} + \dfrac{Cr_{\max}}{1 + \Delta J_i} & \text{otherwise} \end{cases} \quad (9)$$

where $\Delta J_i = \left| J(\vec{V}_i) - J(\vec{X}_{best}) \right|$, Cr_{min}=0.1,Cr_{max}=0.7 and Cr_{const}=0.95

The parameter Cr_i is updated automatically depending on the value of the cost function produced by the donor vector. If the donor vector yields a cost value lesser than the minimum value attained by that population, Cr_i value is chosen high to pass more genetic information into the trial vector otherwise it remains small. Cr_i is determined accordingly.

C. Selection:

Selection decides whether the target vector survives to the next generation or not. The trial vector is compared with the target vector using the following criterion.

$$\vec{X}_{i,G+1} = \begin{cases} \vec{U}_{i,G} & \text{if } J(\vec{U}_{i,G}) \le J(\vec{X}_{i,G}) \\ \vec{X}_{i,G} & \text{if } J(\vec{U}_{i,G}) > J(\vec{X}_{i,G}) \end{cases} \quad (10)$$

If the trial vector has an equal or better objective value then it replaces the corresponding target vector in the next generation. Otherwise the target is retained in the population. DE is an elitist method since the best population member is always preserved and the average objective value of the population will never deteriorate.

IV. RESULTS AND DISCUSSIONS

The ADE algorithm presented in the section III is applied for the synthesis of radiation pattern with desired SLL and null placement control. We consider a uniform circular array of 30 isotropic sources spaced at 0.5λ apart. We use symmetric excitation to excite the array in order to obtain the symmetric radiation pattern in both side of the main lobe.

For ADE we use the following parametric setup for both the designing problems.

a. Population size NP=50;
b. Maximum number of cycles =1000.
c. Maximum number of function evaluations = 50000.
d. Scaling Factor *F* and Cross Over rate *Cr* are modified based on the fitness function of individual population as stated by eq.(6), (7) and (9).

Table I Symmetric current amplitude and phase distribution for multiple nulls placement

Element no.	*Current amplitude*	*Current phase*
1 & 16	0.44149	125.99
2 & 17	0.34563	-84.283
3 & 18	0.65367	159.58
4 & 19	0.19039	179.96
5 & 20	0.55123	157.63
6 & 21	0.28761	171.06
7 & 22	0.99772	161.19
8 & 23	0.85224	-154.73
9 & 24	0.99728	171.91
10 & 25	0.55715	-166.73
11 & 26	0.61486	163.89
12 & 27	0.076661	120.98
13 & 28	0.069083	-166.2
14 & 29	0.50619	91.224
15 & 30	0.70678	-106.15

In the first instance we try to find out the optimal pattern for the 30 elements array with desired maximum at 0^0 and multiple prescribed nulls at 42^0 and 78^0 respectively. It is obvious that image nulls would be imposed at -42^0 and -78^0 since the experiment considers symmetric excitation distribution. The peak SLL at the specified null directions is not allowed to exceed -60dB. Otherwise the desired SLL value is fixed at -20dB. ADE is used to optimize the objective function specified in Eq. (2). The dynamic range allowed for elements amplitude and phase perturbation is (0,1) and (-180^0,180^0) respectively. Table I shows the symmetric current amplitude and phase distribution to generate radiation pattern with desired SLL and multiple nulls. Symmetric radiation pattern obtained using the optimized data in theta domain is shown in Fig.2.

It is seen that the array pattern generated has maximum side lobe level equal to -20.05dB. Nulls are imposed at 78^0 and 42^0 with null depth equal to -61.25dB and -62.16dB respectively. The nulls become deeper with wider main beam width. Maximum allowable tolerance in the main beam broadening is chosen not more than 40^0 (FNBW) for this case.

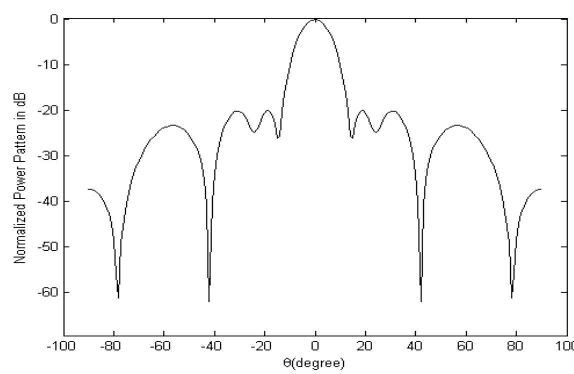

Figure.2. Normalized power pattern with multiple nulls

Table II. Symmetric current amplitude and phase distribution for wide null placement

Element no.	*Current amplitude*	*Current phase*
1 & 16	0.2416	-87.779
2 & 17	0.86115	122.8
3 & 18	0.45376	13.828
4 & 19	0.35613	14.011
5 & 20	0.18861	96.926
6 & 21	0.83597	44.482
7 & 22	0.70913	50.468
8 & 23	0.98333	37.775
9 & 24	0.51488	6.8544
10 & 25	0.99952	18.482
11 & 26	0.55145	60.239
12 & 27	0.12617	126.18
13 & 28	0.76748	-42.62

14 & 29	0.36512	107.14
15 & 30	0.23442	-17.456

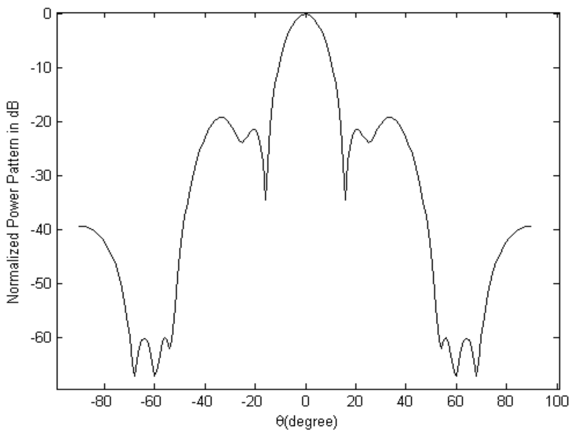

Fig.3. Normalized power pattern with wide null

In the second instance optimal pattern is generated using the same 30 elements array with desired maximum at 0^0 with desired wide nulls located within 55^0 to 70^0. It is obvious that the symmetric nulls would be imposed between -70^0 to -55^0 as the designed instance considers symmetric excitation distribution like the first case. It is expected that the ADE suppresses the array pattern more than -60dB at the specified null regions. Maximum side lobe level is constrained not to exceed -20dB. The null depth it is desired to keep -40dB relative to the peak SLL.

Table II shows the symmetric current amplitude and phase distribution to generate radiation pattern with desired SLL and wide nulls. The dynamic range allowed for elements amplitude and phase perturbation is (0,1) and (-180^0,180^0) respectively. Symmetric radiation pattern obtained in theta domain is presented in Fig. 3. Table III shows desired and obtained results for deep and wide null synthesis.

The maximum side lobe level obtained in this case is equal to -19.17dB whereas the depth of the imposed wide null is found -60dB. SLL as well as depth of the nulls both can be improved with wider main beam width. Maximum allowable tolerance in the main beam broadening is kept within 40^0 (FNBW) like before.

Table III. Desired and obtained results for deep and wide null synthesis

Design Parameters	***Multiple Deep Nulls Synthesis***		***Wide Nulls Synthesis***	
	Desired	***Obtained***	***Obtained***	***Desired***
Side Lobe Level in dB	-20.00	-20.05	-20.00	-19.17
AF at $\pm 78^0$	-60.00	-61.25	NA	NA
AF at $\pm 42^0$	-60.00	-62.16	NA	NA
AF from -70^0 to -55^0 and 55^0 to 70^0	NA	NA	-60.00	-60.00

V. CONCLUSIONS

Designing uniform circular antenna arrays with desired SLL and null placement control in specific directions is a challenging optimization problem in computational electromagnetics.

This paper illustrated the use of an improved variant of DE algorithm for the synthesis of the uniform circular array with desired side lobe level and null placement control.

We formulated the design problem as an optimization task on the basis of a cost function that takes care of the maximum side lobe levels and the null control. The cost function is minimized satisfying both the constraints.

ADE was successfully used to optimize the excitation current amplitude and phase distributions of the array in order to generate an array pattern with desired specifications. Moreover the patterns, amplitude and phase distributions are all symmetric in nature that greatly simplifies the feed network.

Future research may focus on exploring the design of other array geometries and concentric circular arrays with ADE or some more improved population based metaheuristic algorithms.

VI. REFERENCES

[1]. Haupt, R.L, ”Thinned arrays using genetic algorithms”, IEEE Trans. Antennas Propagat.42, 993–999,1994.

[2]. R.L.Haupt, "Adaptive Nulling with Weight Constraints", Progress In Electromagnetics Research B, Vol. 26, 23-38, 2010.

[3]. S. A. Hosseini and Z. Atlasbaf, "Optimization of side lobe level and fixing quasi-nulls in both of the sum and difference patterns by using continuous ant colony optimization (ACO) method", *Progress In Electromagnetics Research*, Vol. 79, 321-337, 2008.

[4]. Jin, N. and Rahmat-Samii, Y, “Advances in particle swarm optimization for antenna designs: Real-number, binary, single-objective and multiobjective implementations”, IEEE Trans. Antennas Propag, 55, 556-567,2007.

[5]. N. N. Pathak, B. Basu, and G. K. Mahanti, "Combination of inverse fast fourier transform and modified particle swarm optimization for synthesis of thinned mutually coupled linear array of parallel half-wave length dipole antennas", *Progress In Electromagnetics Research M*, Vol. 16, 105-115, 2011.

[6]. N. I. Dib, S. K. Goudos, And H. Muhsen, "Application of Taguchi's Optimization Method And Self-Adaptive Differential Evolution to the Synthesis of Linear Antenna Arrays", Progress In Electromagnetics Research, Vol. 102, 159-180, 2010.

[7]. A. Chowdhury, A. Ghosh, R. Giri, and S. Das, "Optimization of antenna configuration with a fitness-adaptive differential evolution algorithm", *Progress In Electromagnetics Research B*, Vol. 26, 291-319, 2010.

[8]. Karaboga, D., K. Guney, and A. Akdagli, “Antenna array pattern nulling by controlling both the amplitude and the phase using modified touring ant colony optimization algorithm," Int. Journal of Electronics, Vol. 91, 241-251, 2004.

[9]. Guney, K. and A. Akdagli, “Null steering of linear antenna arrays using a modified tabu search algorithm",

Progress In Electromagnetics Research, PIER 33, 167-182, 2001.

[10]. Guney, K. and M. Onay, “Amplitude-only pattern nulling of linear antenna arrays with the use of bees algorithm", Progress In Electromagnetics Research, PIER 70, 21-36, 2007.

[11]. Babayigit, B., A. Akdagli, and K. Guney, “A clonal selection algorithm for null synthesizing of linear antenna arrays by amplitude control", Journal of electromagnetic Waves and Applications, Vol. 20, No. 8, 1007-1020, 2006.

[12]. Haupt, R. L., “Phase-only adaptive nulling with a genetic algorithm", IEEE Transactions on Antennas and Propagation, Vol. 45, 1009-1015, 1997.

[13]. Mouhamadou, M., P. Armand, P. Vaudon, and M. Rammal, “Interference supression of the linear antenna arrays controlled by phase with use of SQP algorithm", Progress In Electromagnetics Research, PIER 59, 251-265, 2006.

[14]. Ismail, T. H. and M. M. Dawoud, “Null steering in phased arrays by controlling the element positions", IEEE Transactions on Antennas and Propagation, Vol. 39, 1561-1566, 1991.

[15]. Akdagli, A., K. Guney, and D. Karaboga, “Pattern nulling of linear antenna arrays by controlling only the element positions with the use of improved touring ant colony optimization algorithm", Journal of Electromagnetic Waves and Applications, Vol. 16, No. 10, 1423-1441, 2002.

[16]. Gourab Ghosh Roy, Swagatam Das, Prithwish Chakraborty, and Ponnuthurai N. Suganthan, "Design of Non-Uniform Circular Antenna Arrays Using a Modified Invasive Weed Optimization Algorithm", IEEE Transactions on Antennas and Propagation, Vol. 59, No. 1, 2011.

[17]. M. A. Panduro, C. A. Brizuela, L. I. Balderas, and D. A. Acosta, "A comparison of genetic algorithms, particle swarm optimization and the differential evolution method for the design of scannable circular antenna arrays", *Progress In Electromagnetics Research B*, Vol. 13, 171-186, 2009.

[18]. Storn, R. and Price, K. V. ”Differential Evolution–a simple and efficient heuristic for global optimization over continuous spaces”, J. Global Optimization,11, 341–359, 1997.

[19]. Storn R., Price K. V., and Lampinen, J, ”Differential Evolution–A Practical Approach to Global Optimization”, Springer-Verlag, Berlin, Germany, 2005.