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Synthesis of Hexagonal Antenna Array using Firefly Algorithm

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Abstract

In this paper, the synthesis of Concentric Hexagonal Antenna Array (CHAA) that can generate directive beam with minimum relative Sidelobe Level (SLL) is described. The Firefly Algorithm (FA) method, which represents a brand new method for optimization problems in electromagnetics, is applied for the synthesis of CHAA to enhance the radiation pattern with maximum SLL reduction. A 10-ring uniform hexagonal antenna array with central element is considered. Two examples are provided that illustrate the effectiveness of the FA algorithm. In the first example, FA is used to determine the excitation coefficients of the nonuniformly excited CHAA. In the second example, an strive is made to design a thinned Hexagonal dipole array with tapered amplitude distribution for sidelobe reduction. FA is applied to compute the distributions of ON and OFF elements along with the nonuniform excitation amplitudes applied on ON elements. The numerically simulated power patterns are obtained and compared with those of Concentric Hexagonal isotropic arrays.

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Keywords— Hexagonal array, Thinning, Sidelobe level, Firefly Algorithm

Introduction

Antenna array has been broadly utilized in a significant kind of applications together with direction finding, scanning, Radar, Sonar and wireless communications. They are optimistic in excessive power transmission, low power consumption and more advantageous spectral efficiency [1]. Smart antennas confer with a bunch of antenna technologies that broaden the process potential with the aid of lowering the co channel interference and develop the great with the aid of decreasing the fading effects [2].

The possible advantage results from the symmetry of the circular array structure. On account that a circular array does not have aspect elements, directional patterns synthesized with a circular array can be electronically steered in the plane of the array without a massive change of the beam form. Alternatively, a circular array is high sidelobe geometry [3]. For mitigating high sidelobe levels multi-ring arrays are utilized, which have some other benefits as good [4].

Array Thinning approach turning off some elements in a uniformly spaced or periodic array to generate a pattern with low SLL. In this proposed method, the locations of the factors are constant and the entire factors have two states either “on” or “off” (similar to good judgment “1” and “0” in digital area), relying on whether the array element is attached to the feed network or not. Via thinning of antenna array, number of antenna elements may also be diminished the place array performance will not be drastically degraded. A further potential is the large side lobes are effectively eradicated in thinned array. There are Many published articles [5] coping with the synthesis of thinned array. Schwartzman described the antenna array element behavior in a thinned array [6].

However, most of the authors reported array thinning with uniform excitation amplitudes. Therefore, an attempt is made to design a thinned Hexagonal dipole array with tapered amplitude distribution for sidelobe reduction. A new population based optimization method Firefly Algorithm is employed for thinning a Concentric Hexagonal Dipole Array antenna so as to reduce overall design cost of CHAA. Two Examples are considered: first case optimizes the excitation coefficients of the uniformly excited dipole array for sidelobe reduction. Second designing instance calculates the nonuniform excitations as well as turned on elements for thinned CHAA with dipole radiators.

The Problem Description

A ten-ring uniform Concentric Hexagonal dipole array of ring radius a_m and inter- element gap for a ring d_m for m^{th} ring with centre element is considered [7-8].

The far field radiation pattern of the concentric dipole ring array with single element at the centre is then given by

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$$F(\theta) = EP(\theta) * AF(\theta) \tag{1}$$

Where $EP(\theta)$ gives the element pattern while $AF(\theta)$ is the array factor of the CCAA.

The dipole element pattern is given by [9]

$$\mathrm{EP}(\theta) = \left(\frac{\cos(\mathrm{KL}\cos(\theta) - \cos(\mathrm{KL})}{\sin\theta} \right) \tag{2}$$

Array factor of CHAA can be given below

$$AF = 1 + \sum_{m=1}^{M} \sum_{n=1}^{N_m} \sum_{q=1}^{6} e^{\,jk r_{mnq} \sin\theta \cos(\phi - \phi_{mn})} \tag{3}$$

Where

N_m = Number of elements in the triangular section on m[th] ring,

$N = 1 + \sum_m N_m$

K = 2π/λ= Wave number

$\{\theta, \phi\}$= angular co-ordinate of all points in the visible region of the array

$\{r_{mnq}, \phi_{mnq}\}$ = The co-ordinates of l^{th} element of n^{th} side of m^{th} ring in one angular sector of the array geometry.

Given radius a_m and inter- element gap for a ring d_m for m^{th} ring, r_{mnq}, ϕ_{mnq} and N_m can be calculated as

$$N_m = \left[\frac{a_m}{d_m} \right]$$

$$r_{mnq} = \sqrt{a_m^2 + (n-1)^2 d_m^2 - a(n-1)d_m}, \qquad n = 1,2,3\ldots N_m$$

$$\phi_{mnq} = \cos^{-1\left(\frac{r_{mnq}^2 + r_{mnq-1}^2 - d_m^2}{2 l_{n-1} l_n} \right) + \frac{(q-1)\pi}{3}}$$

The power pattern in dB can be expressed as

$$P(\theta) = 20\log_{10}\left[\frac{F(\theta)}{|F(\theta)|_{\max}} \right] \tag{4}$$

The goal of optimization task in the two antenna designing problems is to minimize the maximum SLL. To accomplish these two designs, the technique of Firefly algorithm (FA) is used. Thus, the fitness function is defined with the evaluation of maximum sidelobe level as

$$Fitness = \max_{\theta \in S} \left| \frac{P(\theta)}{P(\theta_o)} \right| \tag{5}$$

Here, S is the space spanned by the angle θ excluding the main lobe

Firefly Algorithm

Firefly Algorithm (FA) is the lone of the most recent swarm intelligence metaheuristics. In this algorithm the search is stimulated by the flashing behaviour of fireflies and the happening of bioluminescent communication. The flashing light helps fireflies for finding mates to attract their potential prey and defending themselves from their predators [10].

The progress of firefly algorithm is based on three idealized set of rules:

1. All fireflies are unisex
2. Attractiveness is directly proportional to their brightness and decreases with the distance between them increases.
3. The brightness of a firefly which is affected and determined by the allocation of the objective function.

In regulate to design FA, there are two important issues which are need to be defined as follows: (a). The deviation of the light intensity, (b). Formulation of the attractiveness of fireflies. In the Firefly Algorithm, the light intensity I of a firefly is directly proportional to the value of fitness function I(s) α f(s), where s which denotes solution.

The light intensity I(r) vary according to the subsequent equation:

$$I(r) = I_o \exp\left(-\gamma r^2\right) \tag{6}$$

Where I_o represents the light intensity of source and γ is the light absorption coefficient which can be taken as constant. The firefly's attractiveness is directly proportional to that of light intensity seen by nearby fireflies. Therefore, the attractiveness β of a firefly is defined by

$$\beta(r) = \beta_o * \exp\left(-\gamma r_{ij}^2\right) \tag{7}$$

Where β_o is a constant in the presents of the attractiveness at γ =0. The distance among any two fireflies x_i and x_j are articulated as the Cartesian distance

$$\gamma_{ij} = \left|x_i - x_j\right| = \sqrt{\sum_{k=1}^{n}\left(x_{ij} - x_{jk}\right)^2} \tag{8}$$

The progress of a firefly i is attracted to a different brighter firefly j is given by the subsequent equation:

$$x_i = x_i + \beta_o * \exp\left(-\gamma r_{ij}^2\right) * \left(x_j - x_i\right) + \alpha * \left(rand - 1/2\right) \tag{9}$$

In the above equation α indicates randomization parameter which controls the step size. The brightness of a firefly and the attractiveness of each firefly are calculated at every iterative step. The positions of the fireflies are updated according to these values. All fireflies meet to the best probable position on the searching space after an adequate quantity of iterations.

Results

A planar array of 10 Concentric Hexagonal rings with center element is considered. The radii of the rings are a_m (m^{th} ring) and the inter element spacing of elements in each ring is kept at d_m=0.5λ.The number of elements in the m^{th} ring is found out by the values of N_m=a_m/ d_m and the total number of elements becomes 330. The synthesis of planar array of 10-ring Hexagonal dipole array is described in two examples.

Example 1:

The FA is applied to optimize the excitation coefficients of 10-ring concentric hexagonal dipole array. The obtained power pattern is compared with the pattern of Isotropic array. The normalized power patterns are shown in Fig. 1 and amplitude distributions are given in Table 1. The lowest SLL obtained for CHAA synthesis is -43.4dB

Example 2:

For such a fully populated and uniformly excited hexagonal dipole array, FA is applied to find the optimal set of turn on and turn off elements that will generate pencil beam. Two instantiations of the design problem are considered. In the first case, the uniformly excited array used 44.55% thinning to reduce the SLL to -28.76 dB. Distribution of turned ON and turned OFF elements are given in Table 2.The normalized power patterns of a thinned 10-ring Isotropic and dipole CHAA are presented in Figure 2.

In the second case, the distributions of turned ON and turned OFF elements along with the nonuniform excitations applied on turned ON elements is computed using FA. Use of nonuniform excitations reduced the SLL to -32.83dB using 41.81% thinning. Distribution of turned ON and turned OFF elements and nonuniform amplitude excitations are given in Table 3. The normalized power patterns of a thinned 10-ring isotropic and dipole CHAA are shown in Figure 3.

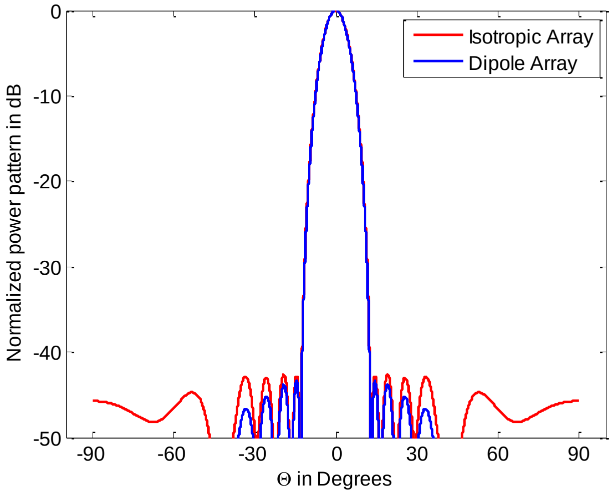

Figure 1: Normalized power patterns of a 10-ring Isotropic and Dipole CHAA using FA

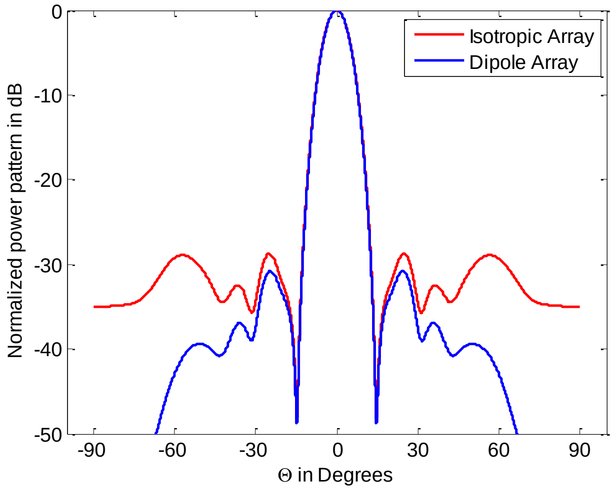

Figure 2: Normalized power patterns of the uniformly excited Thinned 10-ring Isotropic and Dipole CHAA using FA

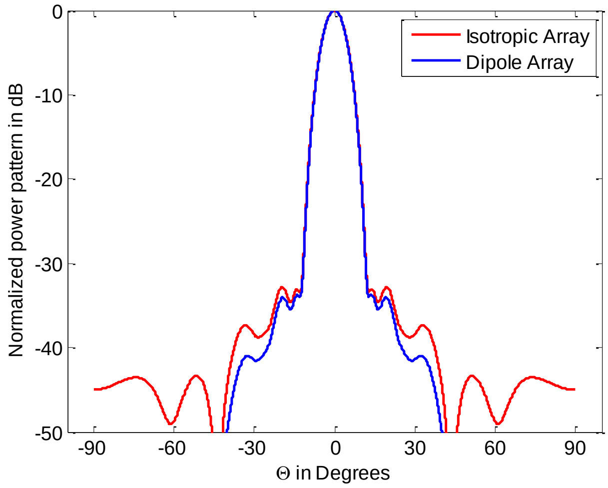

Figure 3: Normalized power patterns of the nonuniformly excited Thinned 10-ring Isotropic and Dipole CHAA using FA

Conclusion

This paper illustrates the synthesis of ten-ring Concentric Hexagonal Antenna Array (CHAA) with dipole radiators for maximum SLL reduction. The novel metaheuristic algorithm FA is applied to achieve the optimal designs. For the first example, the simulation result shows that the maximum SLL of antenna array pattern can be brought down to -43.4dB using FA. In the second example, the method of thinning of a concentric ten-ring Hexagonal array of dipole elements using firefly algorithm to reduce sidelobe level is described. It is evident from the results that use of nonuniform amplitude excitations in the thinned array reduces the SLL more effectively. The proposed algorithm can readily be applied in other geometries to design various array patterns.

Table 1:
Optimized amplitude distribution of the 10-ring array using FA

m	Current amplitude distribution
1	0.4884,0.5276,0.5607,0.4991,0.5871,0.4923
2	0.4618,0.5819,0.5052,0.3928,0.5422,0.4903,0.5193,0.4925,0.4309,0.4391,0.4828,0.5801
3	0.5004,0.5332,0.5835,0.4866,0.5925,0.4629,0.5096,0.5833,0.5161,0.5517,0.5234,0.5542,0.5766,0.4821 0.5146 0.5206 0.5617 0.4737
4	0.4472,0.4840,0.5395,0.5022,0.4922,0.5062,0.5364,0.5975,0.5394,0.5198,0.6090,0.5416,0.5213,0.4618,0.5184,0.4862,0.5742,0.4920,0.5490,0.5669,0.5213,0.5720,0.4781,0.5079
5	0.3796,0.5729,0.4938,0.4594,0.5076,0.5009,0.5099,0.4660,0.6149,0.5849,0.5184,0.5247,0.5735,0.5423,0.5215,0.5387,0.5024,0.5228,0.5796,0.4782,0.5789,0.5302,0.4444,0.5780,0.5730,0.5503,0.5163,0.5035 0.4500,0.4778
6	0.5353,0.5266,0.5261,0.5346,0.5185,0.4213,0.5042,0.4808,0.5363,0.4973,0.5221,0.5919,0.4623,0.4345,0.4061,0.4423,0.4839,0.4710,0.5205,0.4921,0.5194,0.5383,0.5301,0.5246,0.4906,0.5139,0.5405,0.5390 0.4762,0.5006,0.5124,0.5039,0.4057,0.5638,0.4831,0.5479
7	0.5549,0.4947,0.4235,0.4154,0.4256,0.4466,0.4483,0.4058,0.4595,0.4925,0.4308,0.4044,0.4677,0.4247,0.5237,0.5019,0.4911,0.4922,0.5142,0.5145,0.4547,0.4947,0.4437,0.4855,0.5114,0.4921,0.5221,0.5067,0.5083,0.5385,0.3647,0.4974,0.4976,0.4280,0.4167,0.5002,0.4634,0.4721,0.4778,0.

	5298,0.4964,0.5139
8	0.4384,0.4577,0.5383,0.4951,0.4726,0.5332,0.5088,0.4467,0.4785,0.4882,0.4483,0.4608,0.4638,0.5366,0.4513,0.6334,0.5255,0.4681,0.5399,0.4185,0.5057,0.5291,0.4874,0.4982,0.4743,0.5167,0.5680,0.4681,0.4209,0.5490,0.3953,0.5944,0.4937,0.5023,0.3083,0.5333,0.3792,0.4758,0.4690,0.4984,0.4909,0.4516 0.4731,0.5217,0.5259,0.4724,0.5253,0.5764
9	0.4566,0.4557,0.5126,0.5312,0.5597,0.4920,0.4995,0.4302,0.4944,0.4792,0.4837,0.5294,0.4739,0.5491,0.5613,0.4935,0.5129,0.4650,0.3881,0.4567,0.4702,0.4818,0.5234,0.5283,0.4822,0.4482,0.3952,0.4323,0.5469,0.4743,0.4881,0.5695,0.4011,0.4920,0.4513,0.3992,0.4747,0.5030,0.4868,0.4556,0.4834,0.4864 0.4654,0.5787,0.4953,0.5174,0.5358,0.5872,0.4707,0.5571,0.4671,0.4362,0.5163,0.4821
10	0.4529,0.5021,0.5535,0.4414,0.4402,0.3880,0.5442,0.5154,0.4898,0.4343,0.4700,0.5075,0.4610,0.4882,0.4420,0.5917,0.6287,0.4183,0.5515,0.5156,0.4445,0.5645,0.4259,0.5376,0.4476,0.5705,0.5395,0.5209,0.5459,0.5181,0.5042,0.4980,0.3826,0.4503,0.4620,0.5486,0.4362,0.4998,0.4567,0.4796,0.5026,0.4900, 0.4825,0.5233,0.4595,0.4992,0.4728,0.5324,0.5418,0.6018,0.4575,0.5282,0.3870,0.5159,0.5075,0.5063 0.5730,0.4790,0.5066,0.5456

Table 2:
Distribution of turned on and turned off elements of the uniformly excited thinned 10-ring Isotropic and dipole CHAA using FA

m	Current amplitude distribution
1	111111
2	010110001011
3	101111101010100010
4	011001101100 1001111 01101
5	1110 00111011 111110110 010110110
6	100000010111111111 011111110 0110 010010
7	1001011 1 101110 010011 1101010111011110111 011
8	000110100000010010 0011110 1 100101010 000110101111 00
9	011110110011 1110 0101 10101111011110000010100010000100 00
10	1110010 00011 0011101101111000000011100111 00010101111000000011

Table 3:
Nonuniform amplitude distribution of the Thinned 10-ring Concentric Hexagonal Dipole array

M	Current amplitude distribution
1	0.5722,0,0,0,0.6186,0.5909
2	0.5909,0.6359,0,0.5311,0,0,0.6440,0,0,0.5342,0.5043,0.6359,0.5827
3	0.5816,0.5156,0,0,0.5409,0.5050,0,0.5140,0.5874,0.6445,0.7247,0.6189,0,0,0,0.5869,0.5217,0
4	0,0,0.5692,0,0,0.5300,0.5460,0.6825,0.5337,0.5408,0.6613,0,0,0.5362,0.5832,0.5146,0.5205,0.5459 0.6000,0.5831,0.5838,0.6215,0.6598,0.5524
5	0,0.5191,0,0,0.5214,0.5304,0,0,0.5315,0.5343,0,0,0,0.6265,0.5101,0,0.5160,0.5684,0.5072,0.5695,0.5682 0,0,0.5436,0,0.5503,0,0,0.7403,0.6251
6	0,0.5064,0,0.5168,0,0.6582,0,0,0,0,0.5888,0.5513,0,0,0.5610,0.5084,0,0.5675,0,0,0.5871,0.7292,0.5243 0.5109,0,0.5440,0.5500,0.5836,0,0.6173,0,0.5432,0.6093,0.6404,0.5828,0.5398
7	0.6088,0,0.7023,0.5337,0,0,0.5924,0.5225,0.5202,0.5480,0.5408,0,0,0,0,0.6250,0.5128,0.5918,0.6172,0,0.5130,0,0,0.5909,0.6394,0.5271,0.6568,0.5650,0.6266,0,0,0.6328,0.5498,0.6632,0,0,0.5841,0.5111,0,0,0,0
8	0.5222,0,0,0.5961,0.5503,0.5504,0.5768,0,0.5423,0,0.5208,0.5471,0,0.5493,0.5073,0.5891,0,0.5414,0.6356,0,00.5121,0.6128,0.5654,0.5346,0,0.5178,0,0.5025,0.5619,0.5638,0,0.5256,0.5744,0,0.6297,0,0,0,0,0,0,0 0.5286,0.6348,0,0.5005,0.5157
9	0.5057,0.6425,0,0,0,0.5713,0,0.6000,0.5434,0,0,0,0.5172,0.5657,0.5328,0.5173,0,0,0.5785,0.5794,0.6860,0 0.5244,0.5113,0,0.5272,0.7659,0.5321,0,0.5366,0.5000,0,0.6565,0.6019,0.5925,0.5201,0.5218,0,0.5495,0.5489,0.5226,0,0,0.5050,0,0.5441,0.5825,0.5044,0.5498,0,0.5255,0.5494,0,0.6300
10	0,0,0.5163,0,0.5070,0,0.6046,0,0,0.5368,0,0.5292,0.5316,0.5170,0,0.6146,0,0,0.5609,0.5572,0,0,0,0,0,0.5149,0,0,0.6166,0.5203,0,0,0,0,0.5649,0,0,0.5549,0.5579,0.5622,0.5085,0,0.5046,0,0,0.5067,0,0.5150,0.5163,0.5059,0.5738,0.6370,0,0.5304,0.5676,0,0.6975,0.6855,0,0

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