Conformal Antenna Array Synthesis Using Taguchi Algorithm

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Abstract

In this paper, Taguchi Algorithm is used to design a cylindrical conformal antenna array with desired side lobe level and half power beam width. Results obtained by traditional genetic algorithm and Taguchi algorithm are compared. The desired side lobe level and half power beam width are successfully obtained by Taguchi algorithm more faster than genetic algorithm.

1. Introduction

Conformal antennas are widely used in aircrafts, missiles, automobiles and high speed trains. Conformal antennas are integrated to main structure and don't make additional protrusion. So they can provide good aerodynamic and hydrodynamic performance [1].

Nowadays conformal antenna arrays have attracted more interest especially for applications where planar arrays have inconvenience.

The genetic algorithm was applied to conformal antenna array to obtain low side-lobe-level or achieve desired null-pattern [2,3]. The genetic algorithm is inspired by the processes of evolution [4]. It uses natural selection, cross-over and mutation in order to maintain genetic changes in chromosomes. Chromosomes are used to be input of fitness function and have several number of variables that are to be optimized. The desired number of chromosomes are called population.

Firstly, population is sorted according to fitness values, then better chromosomes are selected for mating. After cross-over and mutation, new population is generated. Offspring chromosomes are parents of next generation. Optimization procedure continues until termination criteria is met.

In this paper, Taguchi Algorithm is used to synthesize conformal antenna arrays. Taguchi method uses orthogonal arrays and signal to noise ratio (SNR) to obtain better offspring. Taguchi Algorithm is more robust and efficient optimization algorithm [5].

2. Taguchi Algorithm

Taguchi method uses orthogonal arrays (OAs) those were presented in the 1940s and have been extensively used in designs. They maintain a systematic and efficient way to define control parameters so the optimum results can be reached with several experiments [6].

An orthogonal array is presented by OA(N,k,s,t), where N is number of experimental runs (rows), k is number of variables (columns), s is number of levels for each factor and t is strength. Two level orthogonal arrays are used in this paper. OA(12,11,2,2) is presented in Table 1 [7].

Table 1. OA(12,11,2,2)

Var. / Exp.	1	2	3	4	5	6	7	8	9	10	11
1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	2	2	2	2	2	2
3	1	1	2	2	2	1	1	1	2	2	2
4	1	2	1	2	2	1	2	2	1	1	2
5	1	2	2	1	2	2	1	2	1	2	1
6	1	2	2	2	1	2	2	1	2	1	1
7	2	1	2	2	1	1	2	2	1	2	1
8	2	1	2	1	2	2	2	1	1	1	2
9	2	1	1	2	2	2	1	2	2	1	1
10	2	2	2	1	1	1	1	2	2	1	2
11	2	2	1	2	1	2	1	1	1	2	2
12	2	2	1	1	2	1	2	1	2	2	1

In Taguchi method signal-to-noise ratio (SNR) is used to be control factor. Aim of Taguchi method is to maximize SNRs by running experiments using orthogonal arrays. The SNR is found by using [6].

$$\eta = -20\log(\text{Fitness}) \tag{1}$$

After generation of first population according to number of chromosomes and variables, two chromosomes are selected randomly from population. For example, two chromosomes(chrom.) and variables(var.) are given in Table 2.

Table 2. Randomly selected two chromosomes

Var. / Chrom.	1	2	3	4	5	6	7	8	9	10	11
Level 1	5	5	5	1	9	9	9	2	10	9	1
Level 2	9	5	3	1	3	8	10	4	7	5	7

Using OA(12,11,2,2) in Table 1 and two chromosomes in Table 2, Table 3 is created. The variable is selected from chromosome level according to levels in orthogonal array. For OA(12,11,2,2), (1,1) value of OA is "1", so variable 1 of chromosome level 1(5) is selected. This process is applied to all variables of OA(12,11,2,2) and new population is created. The variables and their fitness-SNR values are given in Table 3. for experiment(exp.) numbers from 1 to 12.

Table 3. New population and fitness-SNR values

Var. / Exp.	1	2	3	4	5	6	7	8	9	10	11	Fitness	SNR
1	5	5	5	1	9	9	9	2	10	9	1	14,6871	-13.6174
2	5	5	5	1	9	8	10	4	7	5	7	12,8513	-12.2977
3	5	5	3	1	3	9	9	2	7	5	7	15,7608	-14.3420
4	5	5	5	1	3	9	10	4	10	9	7	14,4341	-13.4419
5	5	5	3	1	3	8	9	4	10	5	1	14,9099	-13.7705
6	5	5	3	1	9	8	10	2	7	9	1	14,7417	-13.6550
7	9	5	3	1	9	9	10	4	10	5	1	13,9702	-13.1149
8	9	5	3	1	3	8	10	2	10	9	7	15,9384	-14.4588
9	9	5	5	1	3	8	9	4	7	9	1	15,4771	-14.1536
10	9	5	3	1	9	9	9	4	7	9	7	15,4895	-14.1619
11	9	5	5	1	9	8	9	2	10	5	7	14,4676	-13.4652
12	9	5	5	1	3	9	10	2	7	5	1	14,727	-13.6449

The total effects of the variables can expressed as

$$E_{vl} = sum\ of\ \eta_i\ for\ variable\ v\ at\ level\ l \qquad (2)$$

where i is the experiment number, v is the variable and l is the level number. For a two level problem if $E_{vl}>E_{v2}$, the optimal level is level 1 for variable 1 [8]. For variable 1 in Table 1.,

$E_{11} = \sum_{i=1,2,3,4,5,6} \eta_i = -13.6174 - 12.2977 - 14.3420 - 13.4419 - 13.7705 - 13.6550 = -81.1245$

$E_{12} = \sum_{i=7,8,9,10,11,12} \eta_i = -13.1149 - 14.4588 - 14.1536 - 14.1619 - 13.4652 - 13.6449 = -82.9994$

$E_{91} = \sum_{i=1,4,5,7,8,11} \eta_i = -13.6174 - 13.4419 - 13.7705 - 13.1149 - 14.4588 - 13.4652 = -81.8687$

$E_{91} = \sum_{i=2,3,6,9,10,12} \eta_i = -12.2977 - 14.3420 - 13.6550 - 14.1536 - 14.1619 - 13.6449 = -82.2552$

Table 4. Effects of variables, optimum level and optimum chromosome

Ev1	Ev2	Opt.Level	Opt. Chr.
-81,1244	-82,9993	1	5
-81,9844	-82,1394	1	5
-80,6207	-83,503	1	5
-81,9511	-82,1726	1	1
-80,3121	-83,8116	1	9
-82,3229	-81,8008	2	8
-83,5106	-80,6132	2	10
-83,1833	-80,9404	2	4
-81,8686	-82,2551	1	10
-83,4886	-80,6351	2	5
-81,9564	-82,1674	1	1

First level chromosome is optimal for variable 1 with respect to $E_{11}>E_{12}$. Because of $E_{91}>E_{92}$ first level chromosomes is optimal for variable 9. Same operations is applied to the other variables and Table 4. is build.

In this paper Taguchi algorithm is used to optimize conformal antenna array. Flow chart of algorithm is illustrated in Fig. 1.

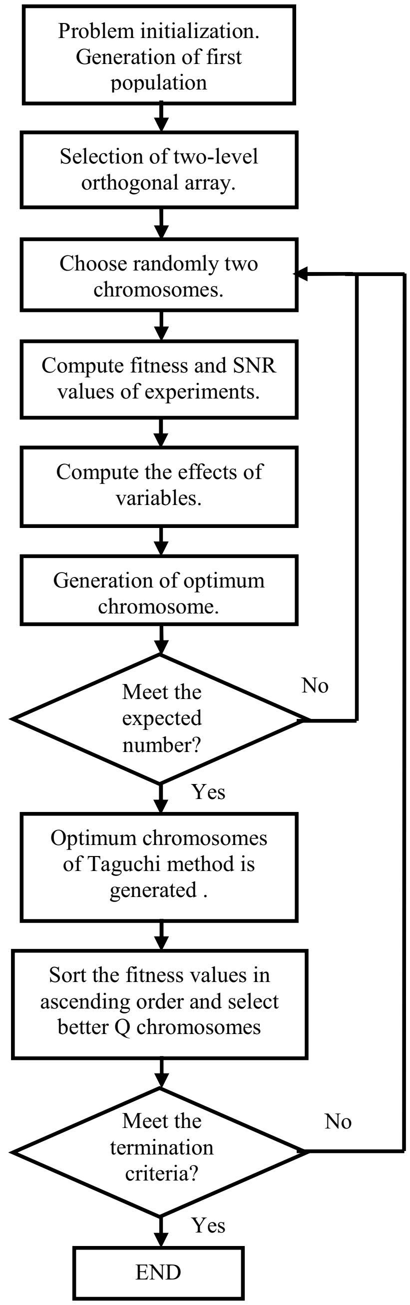

Fig. 1. Flow chart of Taguchi method.

Optimum chromosomes are generated until the expected number $(1/2)xp_cxQ$ has been met [8] where Q is number of chromosomes and p_c is probability of cross-over.

3. Synthesis of Conformal Antenna

The algorithm starts with problem initialization. The proper orthogonal is chosen. There are 28 excitation magnitudes to be optimized. Two level orthogonal array is enough for our problem. So OA(56,28,2,3) is selected [7].

The cylindrical conformal antenna array is presented in Fig.2. The antenna array has 28(MxN=4x7) identical elements. The element spacing is half-wavelength on z-axis.

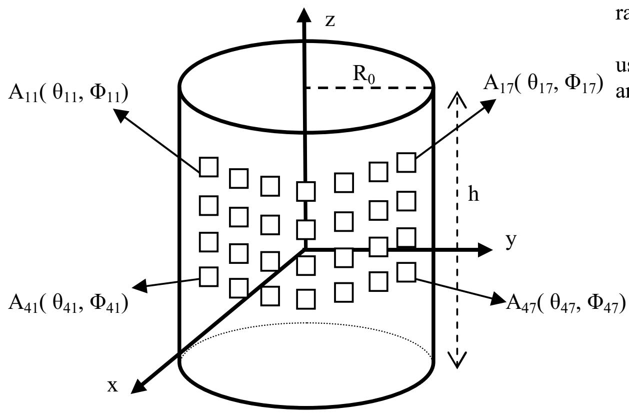

Fig. 2. 4x7(M=1, N=7) cylindrical conformal antenna array.

The array factor for MxN cylindrical conformal antenna array can be written as [9]

$$F(\theta,\Phi) = \sum_{m=1}^{M}\sum_{n=1}^{N} I_{mn} f_{mn}(\theta,\Phi) exp[j[k(A_{mn}(x)sin\theta cos\Phi + A_{mn}(y)sin\theta sin\Phi + A_{mn}(z)cos\theta)] + \varphi_{mn}] \quad (3)$$

where

$$\Phi_{mn} = \frac{\Delta\Phi(2n-N-1)}{2} \quad (4)$$

$$A_{mn}(x) = R_0 cos\Phi_{mn} \quad (5)$$

$$A_{mn}(y) = R_0 sin\Phi_{mn} \quad (6)$$

$$A_{mn}(z) = \frac{d(M-2m+1)}{2} \quad (7)$$

$$\varphi_{mn} = -k[A_{mn}(x)sin\theta_0 cos\Phi_0 + A_{mn}(y)sin\theta_0 sin\Phi_0 + A_{mn}(z)cos\theta_0]. \quad (8)$$

I_{mn} is antenna element excitation amplitude. $f_{mn}(\theta,\Phi)$ is the antenna element pattern. (θ_0, Φ_0) is the desired steering angle. $A_{mn}(x,y,z)$ is position of antenna element on x-y-z axis. $\Delta\Phi$ represents the azimuthal angle difference between adjacent elements in horizontal plane, d is the distance of vertical adjacent elements. R_0 is the radius of cylinder, h is the height of the cylinder. k is the free space wave number($k = 2\pi/\lambda$).

The fitness function is [10];

$$Fitness = w_1.(SLL_{max} - SLL_{comp}) + w_2.(HPBW_{max} - HPBW_{comp}) \quad (9)$$

where SLL_{max} is the desired maximum side lobe level and SLL_{comp} is the computed side lobe level. $HPBW_{max}$ is the desired maximum half power beam width and $HPBW_{comp}$ is the computed desired maximum half power beam width. w_1 and w_2 are the weight coefficient.

The Taguchi method is applied to 4x7 cylindrical conformal antenna array. The cylinder has height(h) of 360.6mm and a radius(R_0) of 128.8mm.

Identical rectangular microstrip patch antenna elements are used in the array. In Fig. 3. geometry of rectangular microstrip antenna element is shown.

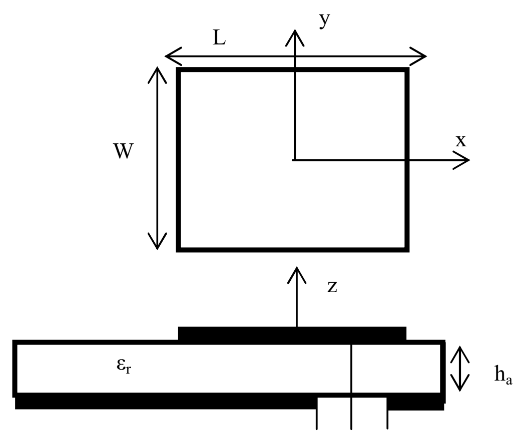

Fig. 3. Geometry of the rectangular microstrip antenna element[11]

Rectangular microstrip antenna has a length of L=18.47mm and a width of W=5mm. Antenna substrate height is h_a= 7.48mm. Relative dielectric permittivity of substrate is ε_r=2.33 [11]. The radiation patterns of rectangular microstrip antenna element is given in Fig. 4.

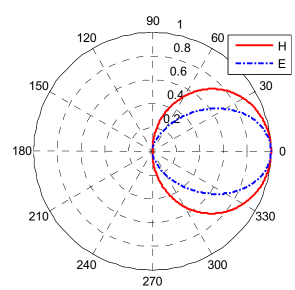

Fig. 4. Normalized radiation pattern for rectangular microstrip antenna in H-plane (y-z plane, solid line) and E-plane (x-z plane, dashed line)

4. Examples

4x7 cylindrical conformal antenna array pattern is synthesized. The aim of the optimization is to obtain the maximum half beam width(HPBW) 0.315 radians for H-plane, 0.85 radians for E-plane and the maximum side lobe level(SLL) -20 dB in E and H-plane.

Number of chromosomes is 50, number of variables is 4x7=28, probability of cross-over is 0.75 and maximum number of generations is 50. w_1 and w_2 in (9) are 1. The excitation magnitudes of antennas are optimized in the range [0, 1].

Optimized radiation pattern is obtained from (4) and illustrated in Fig. 5. Comparison between traditional genetic algorithm and Taguchi method is achieved. Solid line presents the results obtained by Taguchi algorithm and dashed line presents results of genetic algorithm in H-plane with $(\theta_0, \Phi_o)=(0, \pi/2)$ steering angle.

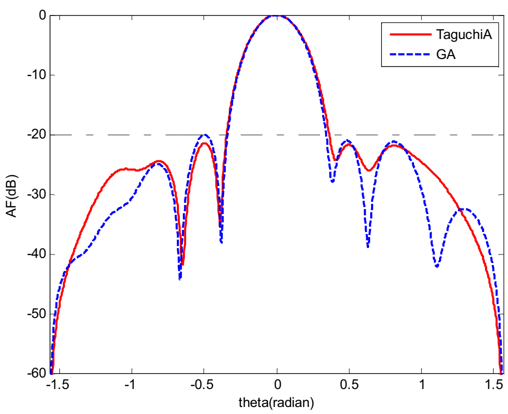

Fig. 5. Normalized radiation pattern of conformal antenna array optimized by Taguchi algorithm and genetic algorithm in H-plane for scan direction $(\theta_0, \Phi_o)= (0, \pi/2)$

Fitness function values of Figure 5. for scan direction $(\theta_0, \Phi_o)= (0, \pi/2)$ in H-plane for Taguchi algorithm and genetic algorithm are shown in Fig. 6.

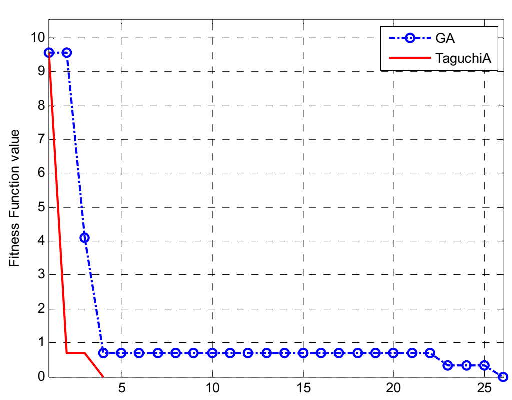

Fig. 6. Comparison of iteration for Taguchi method and genetic algorithm for H-plane

The optimized values of antenna element excitation amplitude obtained by Taguchi algorithm in H-plane for scan direction $(\theta_0, \Phi_o)= (0, \pi/2)$ are given in the Table 5.

Table 5. Optimized antenna element amplitudes of 4x7 conformal array in H-plane for $(\theta_0, \Phi_o)=(0, \pi/2)$

A_{mn}	1	2	3	4	5	6	7
1	0.4730	0.3052	0.7815	0.9543	0.8215	0.3370	0.6324
2	0.0369	0.3618	0.3583	0.8888	0.9530	0.3214	0.1815
3	0.4886	0.4653	0.5577	0.9782	0.0134	0.4570	0.7716
4	0.7521	0.4587	0.4799	0.4988	0.3177	0.1219	0.6099

Optimized radiation pattern in E-plane (x-z plane) for scan direction $(\theta_0, \Phi_o)= (0, \pi/2)$ is shown in Fig. 7.

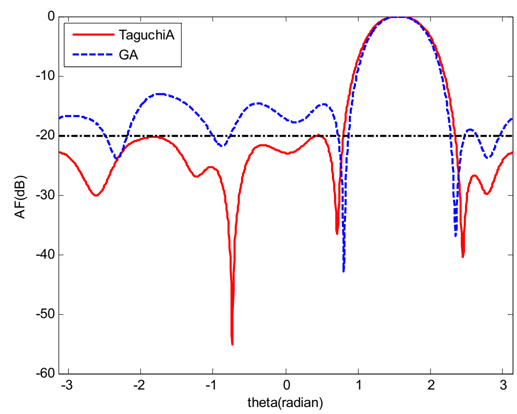

Fig. 7. Normalized radiation pattern of conformal antenna array optimized by Taguchi algorithm and genetic algorithm in E-plane for scan direction $(\theta_0, \Phi_o)= (\pi/2, 0)$

Fitness function values of Figure 7. for scan direction $(\theta_0, \Phi_o)= (\pi/2, 0)$ in e-plane for Taguchi algorithm and genetic algorithm are shown in Fig. 7.

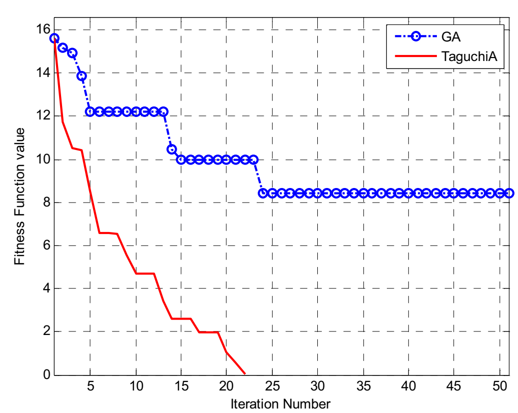

Fig. 8. Comparison of iteration for Taguchi method and genetic algorithm for E-plane

The optimized values of antenna element excitation amplitude obtained by Taguchi algorithm in E-plane for scan direction $(\theta_0, \Phi_o)= (\pi/2, 0)$ are given in the Table 6.

Table 6. Optimized antenna element amplitudes of 4x7 conformal array in E-plane for $(\theta_0, \Phi_o)=(\pi/2, 0)$

A_{mn}	1	2	3	4	5	6	7
1	0.1933	0.2585	0.2669	0.4307	0.0493	0.3957	0.5329
2	0.8525	0.8839	0.4192	0.7343	0.6524	0.5395	0.9825
3	0.8998	0.8082	0.5423	0.8481	0.5244	0.4862	0.9528
4	0.3177	0.1750	0.2335	0.2521	0.2677	0.2143	0.5080

5. Conclusion

In this paper, Taguchi algorithm is applied to conformal antenna array synthesis. 4x7 cylindrical conformal antenna array is optimized by using Taguchi algorithm. Optimization goals are selected as -20 dB side lobe level and 0.315 radians half power beam width for H-plane and -20 dB side lobe level and 0.85 radians half power beam width for E-plane. Results show that desired side lobe level and half power beam width are successfully obtained. Genetic algorithm has also been used for the optimization of cylindrical conformal antenna array. Results obtained with genetic algorithm and Taguchi algorithm are compared. Taguchi algorithm is converged faster than genetic algorithm.

6. References

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