Hybrid Optimization Approach to the Pattern Synthesis of Conformal Antenna Array

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Abstract

In this paper, Hybrid Taguchi Genetic Algorithm (HTGA) is used to minimize the side lobe level and to keep half power beam width in certain values for cylindrical conformal antenna array. The HTGA is based on Genetic Algorithm (GA) and Taguchi Algorithm (TA). Results obtained by GA, TA and HTGA are compared. The best results are also compared with the results obtained by HFSS (High Frequency Structural Simulator).

1. Introduction

Conformal antennas are highly desirable for many applications like satellite, military and civil aircrafts and missiles where the surface is curved. Because of the curved surface the planar arrays are not suitable for this type application. Conformal antennas take the shape of the curved surface so they don't interfere aerodynamic and hydrodynamic performance of the structure[1]. Antennas which are designed on curved shapes like cylindrical, spherical, conical and paraboloid are also called conformal antennas.

In this work, global optimization algorithms such that GA, TA and the HTGA are used to synthesize the pattern of cylindrical conformal antenna array with desired side lobe level (SLL) and half power beam width (HPBW). Hybrid Algorithm is the combination of Genetic Algorithm and Taguchi Algorithm [2].

GA has been successfully applied to synthesis of the conformal antenna arrays. Genetic Algorithms are also used in many applications of electronics [3,4]. GA is based on evolution and genetic processes of biology [3]. Natural selection, cross-over and mutation are the important parts of the GA. In GA, chromosomes form population. Chromosomes are the inputs of the error function and consist of genes (variables).

After the generation of initial population, only healthy individuals who can accommodate themselves to specific conditions, can survive (natural selection). Then, these chromosomes go through the cross-over and mutation processes and generate the offspring. The healthy mate chromosomes and the offspring generate the population of the next iteration. The algorithm is terminated when termination criteria is met.

Taguchi Algorithm has been used in various disciplines like chemistry, mechanical, finance and electronics [5]. However, it is not widely used in electromagnetics [6].

TA can produce optimum results with a few trial. To achieve this, it uses orthogonal arrays and signal-to-noise ratio.

Orthogonal arrays are very important for TA. The control parameters are selected by orthogonal array.

Signal-to-noise ratio is used as a control element by transforming great number of trials to a single value. An optimum generation is obtained by using orthogonal array and signal-to noise ratio in TA.

An orthogonal array can be shown as 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 [7]. Number of variables (columns) is selected according to the number of parameters to be optimized. Two level orthogonal arrays OA(56,28,2,3) are used [8].

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

After generation of first population according to number of chromosomes and variables, two chromosomes (levels) are selected randomly from population. A new population is created by using the two chromosomes and OA. After the creation of new population, SNR values of all chromosomes are calculated. Then the total effects of the variables are calculated by using orthogonal array and SNR values of chromosomes.

This process is used for all variables and the offspring chromosome is generated by comparing the effects of levels [9,10]. The variable which has the largest SNR gives the optimal level [6].

In this work, a conformal antenna array with cylindrical surface has been synthesized. Antenna elements of the array are identical rectangular microstrip patch antennas. Microstrip patch antenna elements are used because of easy to manufacture, low-profile and low cost. The desired side lobe level and half power beam width are selected as optimization goal. The magnitudes of excitation currents of antenna elements have been optimized.

Cylindrical conformal antenna array has been simulated by using magnitudes of excitation currents of array elements which are obtained from the algorithm giving the best results. HFSS [11] has been used for simulation. Patterns of HFSS simulation and the algorithm giving the best results have been compared. Optimization results of GA, TA and HTGA are compared with respect to convergence rate, computation time and the error.

2. Hybrid Taguchi-Genetic Algorithm

The Hybrid Taguchi Genetic Algorithm has been proposed by Tsai and others [2].

HTGA consist of GA and TA. The TA is located between cross-over and mutation process of GA. Taguchi method improves the GA by selecting better genes to achieve cross-over. Flow chart of Hybrid Taguchi Genetic Algorithm is shown in Fig. 1.

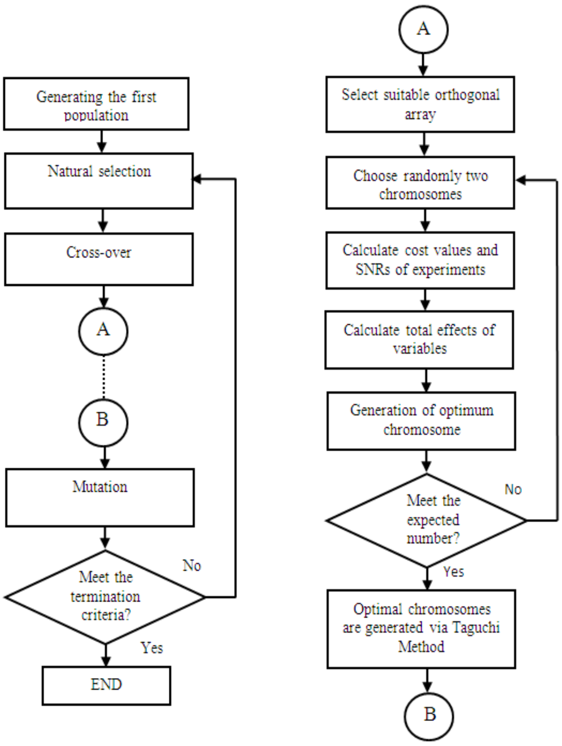

Fig. 1. Flow chart of HTGA [2]

3. Cylindrical Conformal Antenna Array

The cylindrical conformal array have 4x7=28 antenna elements. OA(56,28,2,3) is used to optimize amplitudes of these 28 excitation antenna elements. MxN cylindrical conformal antenna array is given in Fig 2.

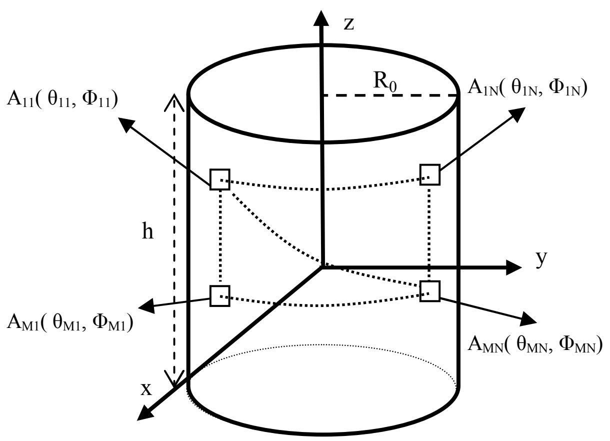

Fig. 2. MxN cylindrical conformal antenna array.

The array factor for MxN cylindrical conformal antenna array can be written as [10]

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

where

$$\varphi_{mn} = -k[A_{mn}(x)sin\theta_0 cos\Phi_0 + A_{mn}(y)sin\theta_0 sin\Phi_0 + A_{mn}(z)cos\theta_0]. \quad (2)$$

$$A_{mn}(x) = R_0 cos\Phi_{mn} \quad (3)$$

$$A_{mn}(y) = R_0 sin\Phi_{mn} \quad (4)$$

$$A_{mn}(z) = \frac{d(M-2m+1)}{2} \quad (5)$$

$$\Phi_{mn} = \frac{\Delta\Phi(2n-N-1)}{2} \quad (6)$$

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 error function is [12];

$$Error = w_1.(SLL_{max} - SLL_{comp}) + w_2.(HPBW_{max} - HPBW_{comp}) \quad (7)$$

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 algorithms are applied to 4x7 cylindrical conformal antenna array. Identical rectangular microstrip patch antenna elements are used in the array. The element spacing is half-wavelength on z-axis. HFSS drawing of 4x7 cylindrical conformal antenna array is given in Fig. 3.

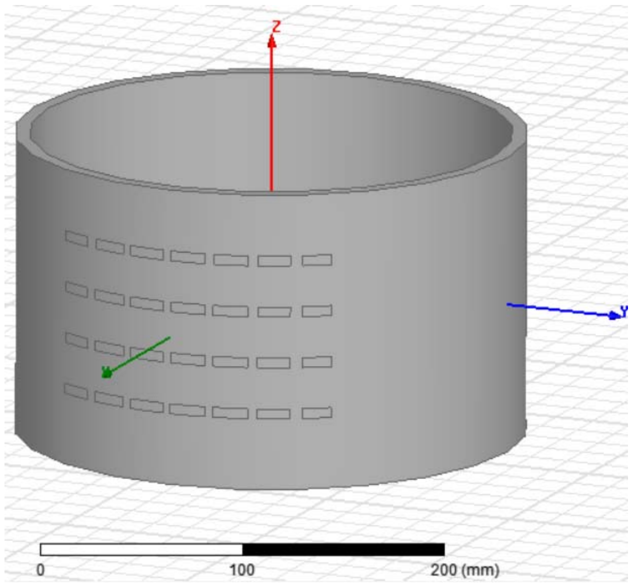

Fig. 3. HFSS drawing of the array

4. Results

4x7 cylindrical conformal antenna array pattern is synthesized using different global optimization algorithms. The aim of the optimization is to obtain the maximum HPBW 0.35 radians for H-plane, 0.85 radians for E-plane and the maximum SLL -20 dB in E and H-plane.

Chosen value of number of chromosomes is 100, number of variables is 4x7=28, probability of cross-over is 0.75, probability of mutation is 0.5 and maximum number of generations is 100. The weights, w_1 and w_2 in (7) are selected as 1. The excitation magnitudes of antennas are optimized in the range {0, 1}.

Radiation pattern is obtained by (1) from the optimization of (7) and shown in Fig. 4 for H-plane. The desired SLL and HPBW have been obtained by TA and HTGA.

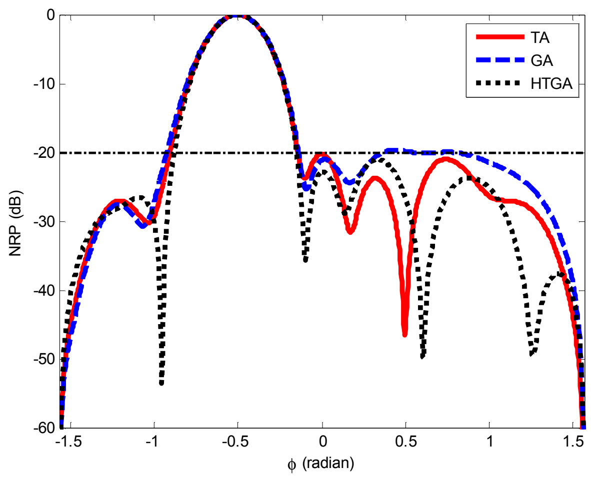

Fig. 4. Normalized radiation pattern of the cylindrical conformal antenna array in H-plane for scan direction (θ_0, Φ_o)= ($\pi/2$,- $\pi/6$)

Error function values for scan direction (θ_0, Φ_o)= ($\pi/2$,- $\pi/6$) in H-plane for TA, GA and HTGA are shown in Fig. 5. TA is converged at 5th iteration, HTGA is converged at 3th iteration. But, GA could not have converged and has reached the maximum number of iterations with maximum value of error

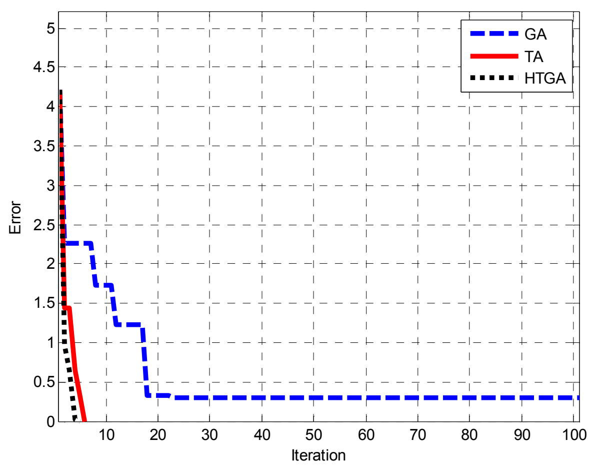

Fig. 5. Convergence of TA, GA and HTGA for H-plane

The antenna element excitation amplitudes obtained by GA, TA and HTGA in H-plane for scan direction (θ_0, Φ_o)= ($\pi/2$,- $\pi/6$) are given in the Table 1.

Table 1. Optimized antenna element amplitudes of 4x7 conformal array in H-plane for (θ_0, Φ_o)=($\pi/2$,- $\pi/6$) a) GA b) TA c) HTGA

a)

I_{mn}	1	2	3	4	5	6	7
1	0,0625	0,3262	0,6081	0,0970	0,9727	0,3661	0,878
2	0,0347	0,8533	0,4724	0,9281	0,9584	0,2653	0,5942
3	0,0282	0,1661	0,8673	0,6645	0,1727	0,8989	0,6152
4	0,9086	0,4938	0,1265	0,9079	0,8763	0,4746	0,1774

b)

I_{mn}	1	2	3	4	5	6	7
1	0,0655	0,0849	0,5963	0,4225	0,2566	0,6004	0,8161
2	0,3172	0,5582	0,4176	0,3331	0,6614	0,7499	0,1348
3	0,0603	0,3925	0,2926	0,5812	0,9980	0,0441	0,0987
4	0,6460	0,2539	0,4991	0,4627	0,5409	0,4673	0,1649

c)

I_{mn}	1	2	3	4	5	6	7
1	0,0385	0,6908	0,9502	0,9964	0,9669	0,4695	0,9413
2	0,1777	0,0710	0,2756	0,8599	0,3506	0,6236	0,2048
3	0,7755	0,9506	0,6544	0,5089	0,7351	0,2069	0,1629
4	0,5756	0,5121	0,9075	0,6577	0,5336	0,4888	0,0364

The result of HFSS simulation are given for the result obtained by HTGA for H-plane with scan direction (θ_0, Φ_o)= ($\pi/2$,- $\pi/6$) in Fig. 6. HTGA and HFSS give similar results for H-plane.

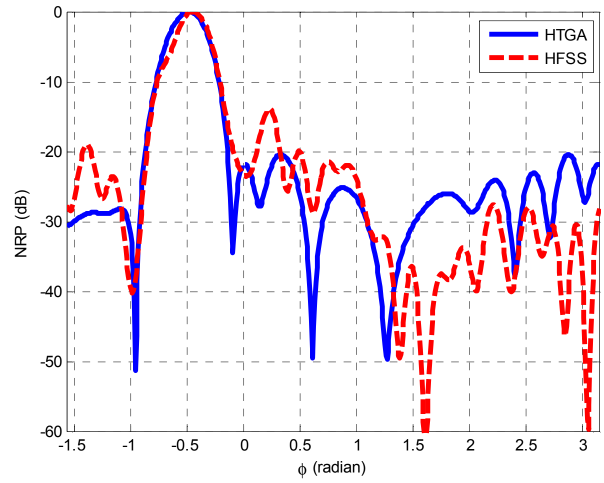

Fig. 6. Normalized radiation pattern of cylindrical conformal antenna array in H-plane for (θ_0, Φ_o)=($\pi/2$,- $\pi/6$)

Optimized radiation pattern in E-plane (x-z plane) for scan direction (θ_0, Φ_o)= ($\pi/2$, -$\pi/6$) is shown in Fig. 7. The desired side lobe level and HPBW has been obtained by TA and HTGA.

Error function values for scan direction (θ_0, Φ_o)= ($\pi/2$, -$\pi/6$) in E-plane for TA, GA and HTGA are shown in Fig. 8. TA is converged at 21st iteration, HTGA is converged at 15th iteration. But, GA could not have converged.

The antenna element excitation amplitudes obtained by GA, TA and HTGA in E-plane for scan direction (θ_0, Φ_o)= ($\pi/2$,- $\pi/6$) are given in the Table 2.

The results of HFSS simulation and HTGA are given in Fig. 9. Similar results are obtained by HTGA and HFSS simulation.

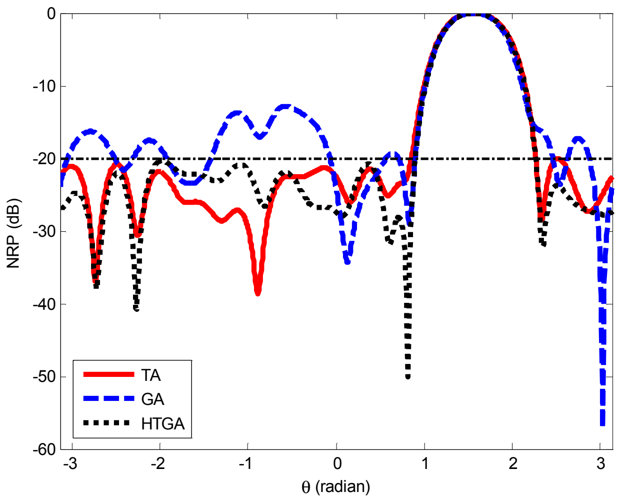

Fig. 7. Normalized radiation pattern of cylindrical conformal antenna array in E-plane for scan direction (θ_0, Φ_o)= ($\pi/2$, -$\pi/6$)

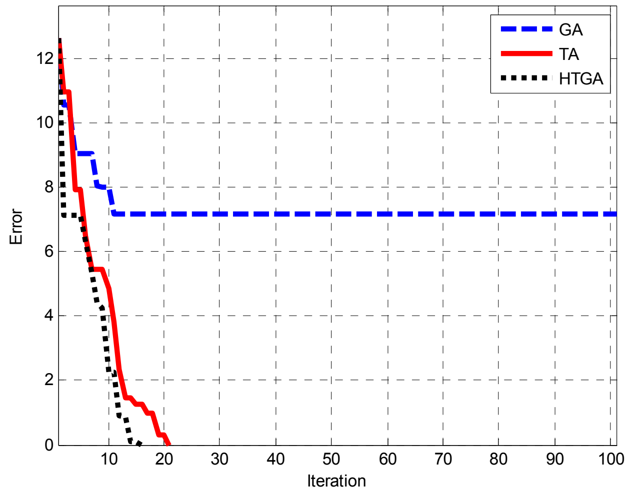

Fig. 8. Convergence of TA, GA and HTGA for E-plane

Table 2. Optimized antenna element amplitudes of 4x7 conformal array in E-plane for (θ_0, Φ_o)=($\pi/2$,- $\pi/6$) a) GA b) TA c) HTGA

a)

I_{mn}	1	2	3	4	5	6	7
1	0,6239	0,3095	0,3873	0,4351	0,2287	0,3376	0,4626
2	0,7040	0,9735	0,5202	0,9872	0,5981	0,4399	0,8265
3	0,9730	0,5466	0,4301	0,7513	0,6562	0,0160	0,9494
4	0,2407	0,3955	0,1115	0,4605	0,0910	0,1950	0,6720

b)

I_{mn}	1	2	3	4	5	6	7
1	0,2760	0,2417	0,3786	0,2691	0,4229	0,5341	0,5801
2	0,7297	0,7844	0,6841	0,9970	0,7829	0,9730	0,9337
3	0,8194	0,5238	0,8464	0,9942	0,9689	0,8928	0,9737
4	0,6390	0,0854	0,3264	0,4089	0,4691	0,4333	0,4716

c)

I_{mn}	1	2	3	4	5	6	7
1	0,4898	0,2599	0,2625	0,4253	0,4162	0,4299	0,6260
2	0,7802	0,7067	0,8324	0,8044	0,8944	0,9848	0,8844
3	0,8363	0,5486	0,9711	0,7811	0,7804	0,9917	0,7579
4	0,5402	0,2605	0,4021	0,4668	0,2295	0,3993	0,4200

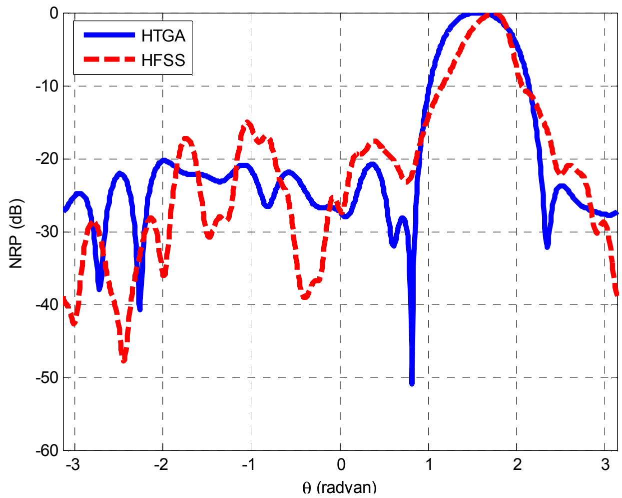

Fig 9. Normalized radiation pattern of cylindrical conformal antenna array in E-plane for (θ_0, Φ_o)=($\pi/2$,- $\pi/6$)

The comparisons of algorithms with respect to total number of iterations, computation time and error for H-plane and E-plane are given in Table 3. HTGA has been converged faster than GA and TA for both planes. GA has reached maximum number of generations with maximum value of error for H and E planes.

Table 3. : Comparison of algorithms a) H-plane b) E-plane.

a)

	Iteration	Computation Time(s)	Error
GA	100	2303.90588	0.2957
TA	5	640.844083	0
HTGA	3	453.762747	0

b)

	Iteration	Computation Time(s)	Error
GA	100	2250.743565	7.1477
TA	21	2680.396109	0
HTGA	15	2235.710679	0

5. Conclusion

In this work, HTGA is applied to the pattern synthesis of a conformal antenna array. 4x7 cylindrical conformal antenna array is optimized by using GA, TA and HTGA. Optimization goals are selected as -20 dB side lobe level and 0.35 radians half power beam width for H-plane, -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 widths are successfully obtained. The results obtained by GA, TA and HTGA are compared. The best results are obtained by HTGA.

The radiation pattern of the cylindrical conformal antenna is simulated by HFSS by using the best excitation amplitude values of HTGA. HFSS and HTGA results are also compared.

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