OPTIMIZATION OF ARRAY FACTOR IN LINEAR ARRAYS USING MODIFIED GENETIC ALGORITHM

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Abstract The array factor (sidelobe level, SLL) of a linear array is optimized using modified continuous genetic algorithms in this work. The amplitudes and phases of the currents as well as the separation of the antennas are all taken as variables to be controlled. The results of the design using modified GA versions are compared with other methods. Two design problems were studied using several continuous modified GA versions and the results are presented as several plots. As a final example, the design specifications for an array with 200 elements are given. The effectiveness and advantages of the proposed modified GA versions are outlined.

Key Words Linear Arrays, Array Factor (AF), Sidelobe Level (SLL) Genetic Algorithm (GA), Optimization

چکیده در این مقاله سطح گلبرگ کناری (SLL) با استفاده از الگوریتم وراثتی پیوسته اصلاح شده بهینه شده است. دامنه، فراز و نیز فاصله آنتن ها همگی به عنوان متغیرهای کنترل کننده در نظر گرفته شده است. نتیجه طراحی با روش های دیگر مقایسه گردیده است. دو نمونه طراحی با چندین نمونه الگوریتم پیوسته ارتقاء یافته بررسی شده اند و نتایج به صورت منحنی های متعدد ارائه گردیده است. به عنوان یک مثال نهایی، مشخصه های یک آرایه بزرگ ۲۰۰ عنصری به دست آمده و مزایا و موثر بودن روش های GA ارائه شده در مقاله در این گونه مسایل تشریح شده است.

1. INTRODUCTION

The application of Genetic Algorithm (GA) is now common in complicated EM problems [1]. In designing arrays with many elements (more than 50), GA is referred to as one of efficient methods [2] which is capable of handling complex problems with many independent variables. Suitable design methods based on conventional procedures have been presented for arrays with fewer elements [3].

In the design of linear and planar arrays, in addition to relative positions, the amplitudes and phases of the elements is critical for a desired specification. In this work, the array factor (AF) is optimized by continuous (Real Coded) GA. The properties of various versions of continuous GA in designing array factors is investigated and to consider the effectiveness of the proposed modified versions the specifications of a linear array, i.e. positions of the elements, amplitudes, and phases of the excitation currents with many elements using modified continuous GA's is presented.

2. PRELIMINARIES

When the positions and the excitations of the elements in an array are known, the array factor, AF (θ,ϕ), can be obtained for different specific geometries [4]. Ordinarily in analysis and design procedures one of the two factors, position or excitation, is used as a variable to optimize the array factor. However in optimization using GA, there is no limitation on selection of variables. Therefore, the amplitudes and phases of the excitations as well as positions of the elements can be used as independent variables in the optimization process.

Normally, phases of excitations, in the elements of an array are multiples of a fixed value which is determined by the number of binary bits of the binary phase shifter. Therefore, all the angles can not be swept practically, by these phase shifters. For example, to realize a precision of 0.5 degrees, a ten bit phase shifter ($2^{10}=1024$) should be employed. Therefore to find the desired accuracy in phases of the elements, delay lines are used. A combination of phase shifter and delay lines can provide an excitation with an arbitrary phase.

In many conventional design techniques, the amplitude of excitation is obtained for elements with equal separations and the far field pattern of the array is controlled by the amplitude of excitation. In some other methods positions of the elements is controlled with an assumed current distribution. The purpose of optimization is reducing the main lobe beamwidth, sidelobe level (SLL) or null position control of the pattern. In this work, the reduction of sidelobe level by controlling amplitudes, phases, and the positions of the elements is performed. The effectiveness of the proposed continuous GA versions in such a complex problem with many variables is studied.

3. GENETIC ALGORITHM

Foundations for GA are well known [5]. In the past decade GA has been used in antenna arrays and antenna pattern design [6]. Sidelobe level reduction for linear and planar arrays has shown that reduction of sidelobe level (SLL, in dB's) is linearly related to the logarithm of the reduction in half-power beam width [7]. In these methods, with an assumption that the positions of all elements of the array are specified, the excitation current is determined using GA. Results show that SLL reduction is readily possible using the presented modified GA methods with significant improvement over conventional genetic algorithm[8].

4. CONTINUOUS GENETIC ALGORITHM

Solving problems in the continuous space, using discrete GA requires in each step of evolution, two mappings; from discrete space to the continuous space and vice versa. Therefore the computational time in this case is much more than that of the continuous GA. In this paper we have used modified continuous GA for arrays with high numbers of elements.

In Table 1, the design conditions using continuous GA for three linear arrays, problems #1 through #3, is indicated. The elements of these arrays are symmetric with respect to center of the array. Since amplitudes and phases of the elements as well as their separations are selected as variables, we have 3N parameters for an N element array. However due to symmetry of the array, we have 3N/2 variables to control for optimizing the problem. The results for the array factors of problems #1 and #2 are given in Figures 1 through 5. These figures show the variations of maximum SLL versus numbers of generations in continuous versions of genetic algorithms. Five different versions of continuous GA, namely C1 through C5 were used in the optimization process. In the continuous genetic algorithm, the space variable is continuous which is a real number ranging from zero to one. The evolution continues in the chromosome space. The superior generations evolve according to the natural selection law and finally, the evolved population is reverse transformed into the variable space. We call this as the conventional genetic algorithm (C1). The difference between the conventional (discrete) GA

TABLE 1. Design Specifications for Problems #1, #2, and #3 in the Continuous GA. The Initial Population Distribution is Uniform.

Description of the Array	Problem # 1	Problem # 2	Problem # 3
No. Elements	128	48	200
No. Variables (dimensions)	192	72	300
No. Population	128	128	512
No. Evolution Stages	200	200	288
Minimum of No. Evolution Stages	$\lambda/2$	$\lambda/4$	$\lambda/2$
Maximum of No. Evolution Stages	λ	$5\lambda/4$	$3\lambda/2$

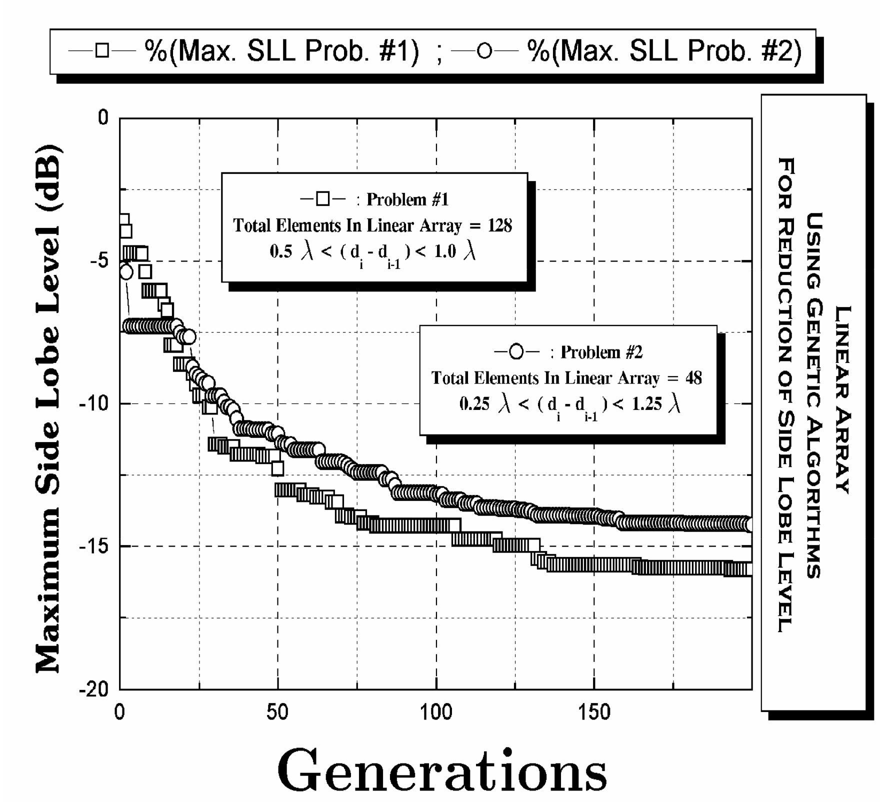

Figure 1. Maximum SLL (dB) of the linear array versus stages of evolution in the conventional continuous GA (C1).

and the continuous GA (real coded) routine are in the following processes:

(a) transformation from the chromosome space to the variable space and the inverse transformation;

(b) the method of mutation of genes; and

(c) the structure of genes (chromosomes).

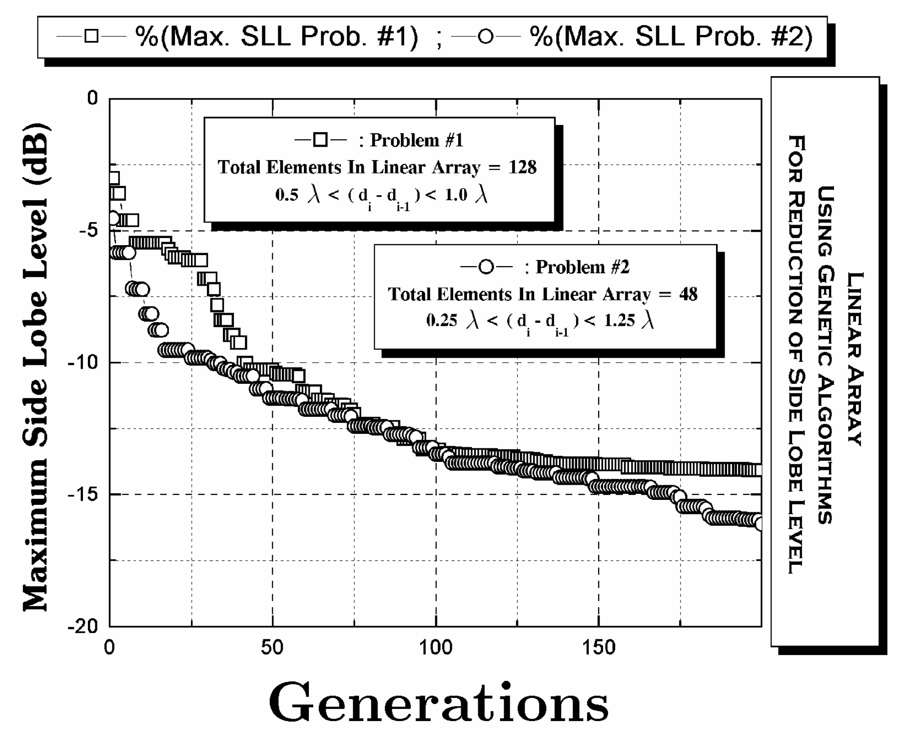

Figure 2. Maximum SLL (dB) of the linear array versus stages of evolution in modified continuous GA (C2).

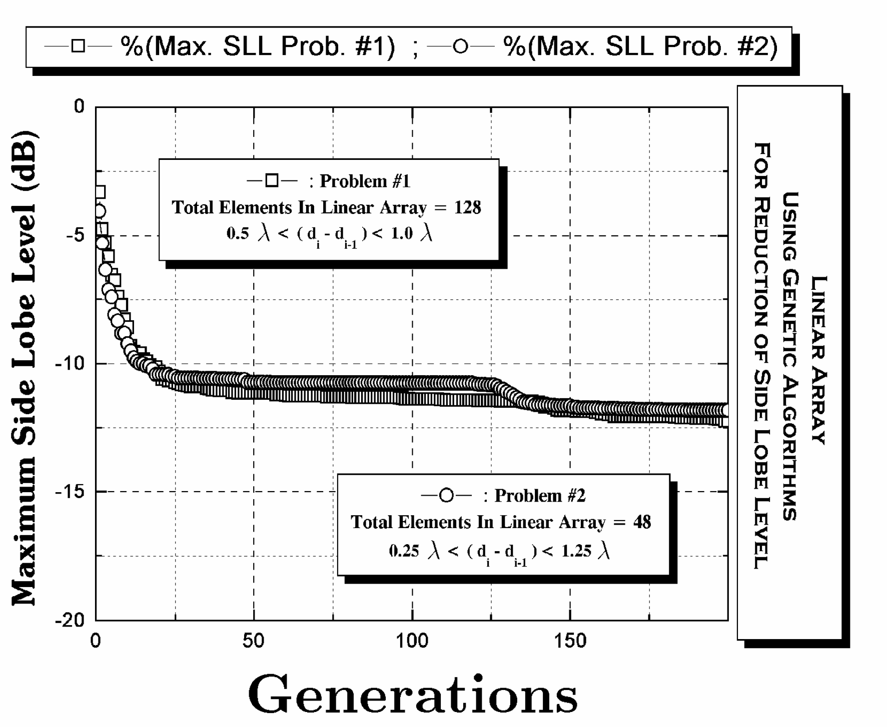

Figure 3. Maximum SLL (dB) of the linear array versus stages of evolution in modified continuous GA (C3).

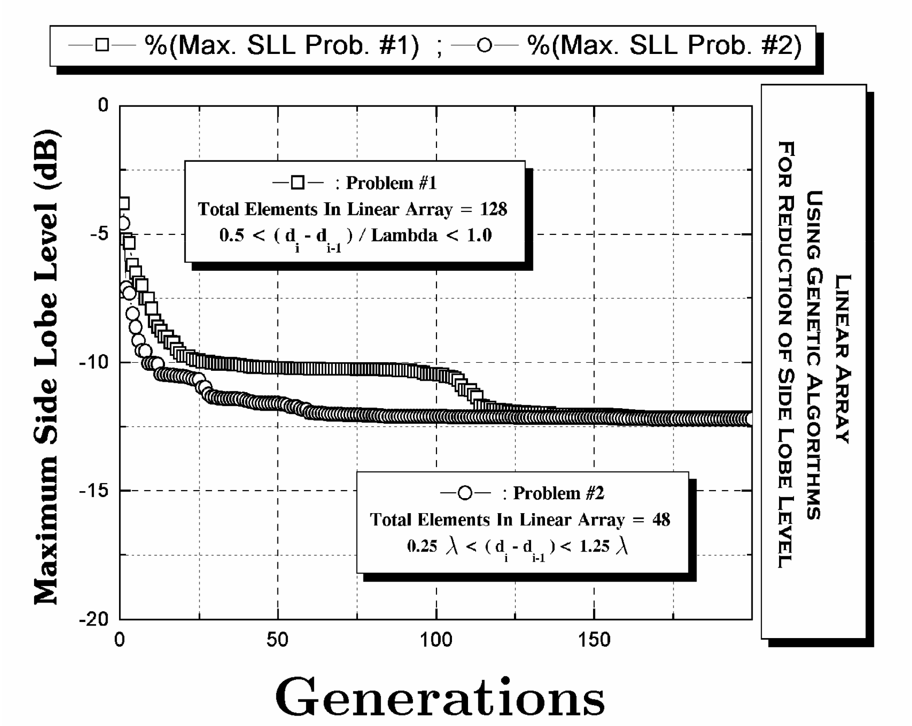

Figure 4. Maximum SLL (dB) of the linear array versus stages of evolution in modified continuous GA (C4).

Other modified GA versions used in the analysis are as follows:

Continuous GA with adaptive mutation rate (C2)

Fast continuous GA with adaptive mutation rate (C3)

Continuous GA with adaptive mutation rate and high mortality (C4)

Fast continuous GA independent of genes “intervals” (C5).

C2: In *continuous GA with adaptive mutation rate* (C2), we control the mutation factor. The direction of mutation rate is selected opposite to the evolution error. If in two consecutive generations, the evolution error increases, we reduce the mutation rate and vice versa. In all versions, however, the best chromosome is not altered. Normally, the rate of increase (or decrease) in mutation is preserved.

C3: In *fast continuous GA with adaptive mutation rate* (C3), the change in the mutation rate has an inverse relation to the total number of chromosomes (individuals) in the population. In other words, in high chromosome population, the rate of change is selected low and vice versa. In (C3) mutation and mating of chromosomes is controlled. If the number of matched chromosomes with the prescribed specifications is increased relative to the total population, then either the probability of evolution or the speed of convergence is increased. To realize the phenomena in each step of evolution, the number of matched chromosomes with desired specifications is increased. A suitable selection for matched chromosomes is a percentage "between" three to seven such that the most matched

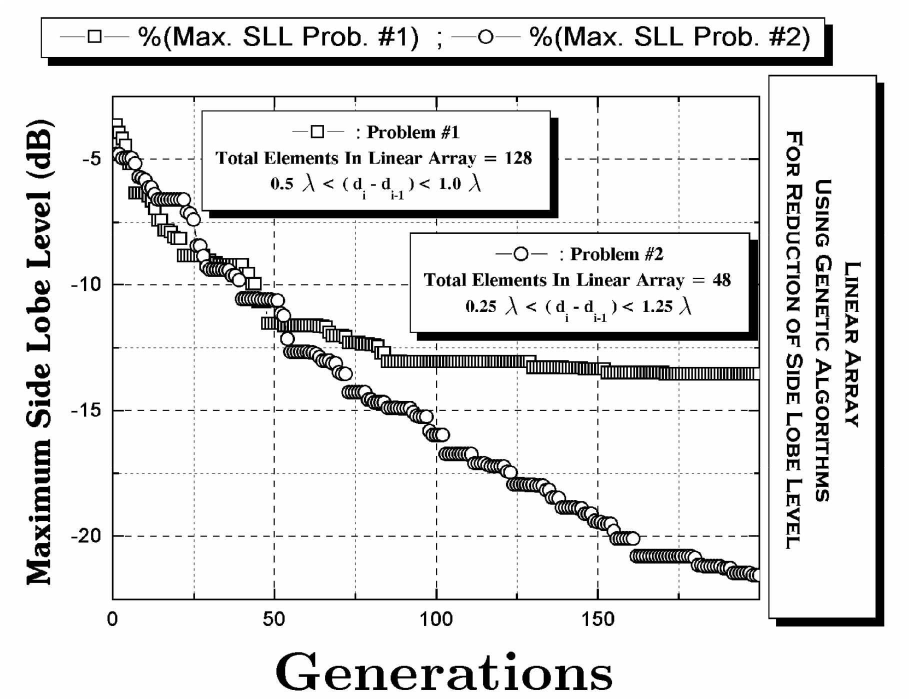

Figure 5. Maximum SLL (dB) of the linear array versus stages of evolution in modified continuous GA (C5).

chromosomes can be taken to be five percent.

C4: If the matched individuals are assumed as a closed loop chain and the replacement of population is done by repetition and combining the loop with itself, then this method is similar to the conventional continuous GA (C1) in which the number of individuals to be eliminated is high in comparison to the total population. In addition, the mutation rate is also adaptive. We refer to this version as: *continuous GA with adaptive mutation rate and high mortality* (C4).

C5: The last modified version of the GA method is *continuous GA independent of genes separations* (C5). Generally, evolution is due to two factors; i.e. mutation and mating. In the continuous space, mutation by many states will provide all the possible values of the variables. In mating, we can either increase the number of crossover points or the position of crossover. In a chromosome model, similar to a DNA, genes are like a chain while in this process a chromosome makes a loop where genes are located around this loop. When mating, a loop has not a beginning or an end and hence crossover becomes independent of the position of the event and the two loops can interchange each part of their periphery. In nature however, according to the experiments, there is a direct relation between the distance of genes and the probability of occurrence of a crossover. With an increase in genes separations, the probability of the occurrence of a crossover is increased and vice versa [9] but in the above technique an independency in the genes separation is achieved.

In Figure 6 the array factor of problem #2 in ϕ=90 plane using modified version (C2) is presented after 200 evolution stages. Figure 7 shows a typical array factor for a uniform linear array with 48 elements in the ϕ=0 plane as a reference. The elements of the array are isotropic with a quarter wavelength separation. A comparison

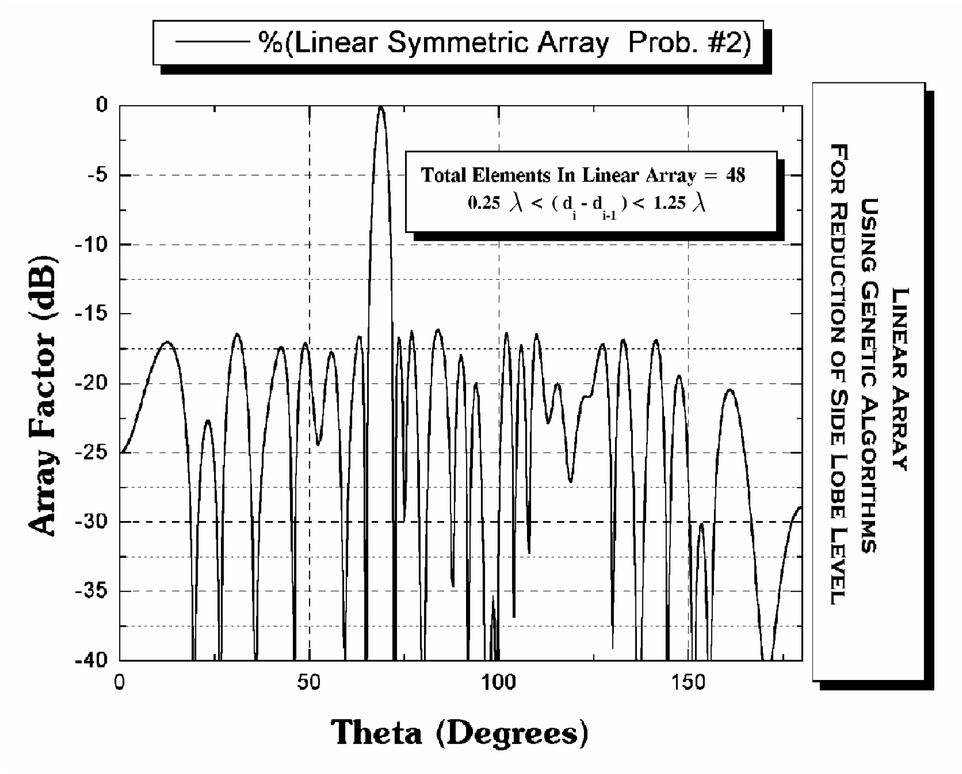

Figure 6. Array factor (AF) of problem #2 versus θ (in degrees) in modified GA (C2) after 200 stages.

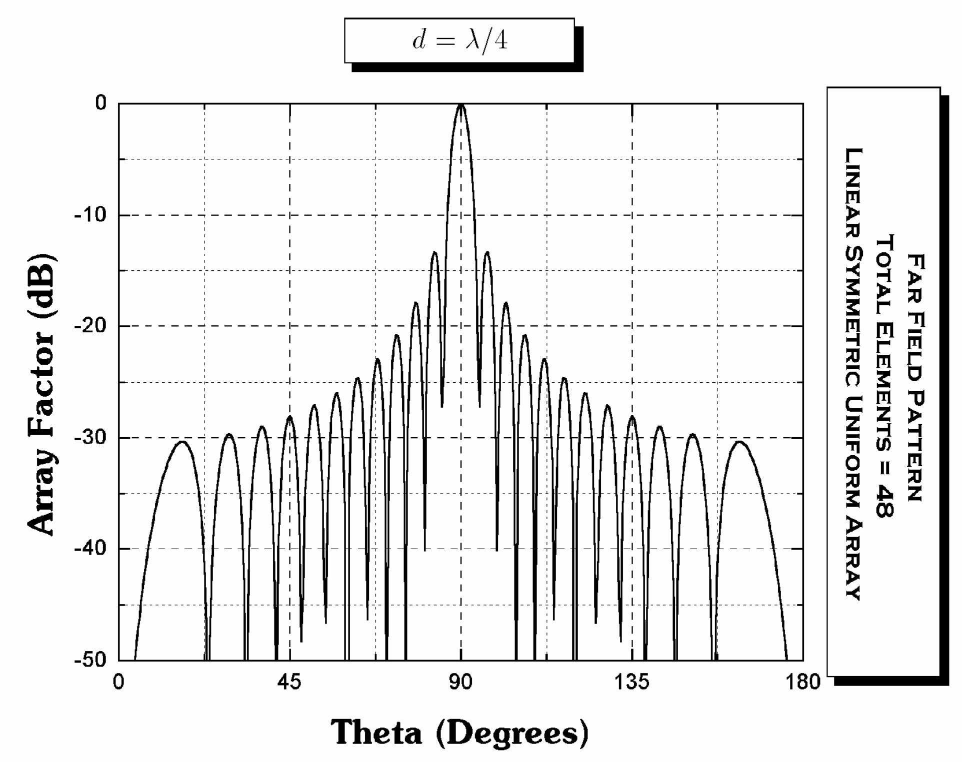

Figure 7. Array factor (AF) for a uniform linear array with 48 elements and a separation of d=λ/4.

of Figure 6 and Figure 7 shows several dB improvement in the SLL using modified version (C2). Even more improvement can be achieved using other versions.

5. DESIGN RESULTS USING MODIFIED ALGORITHMS

As a design example using modified GA versions, we select a complicated case (problem #3). The proposed data is given in Table 1. We have used version (C5) in the design procedure. The elements of the array are symmetric around center of the array. There are 200 elements in the array and therefore, considering symmetry of the problem we have 300 independent variables which are phase, amplitude and the position of each element. The results of SLL and relative processing time of the algorithm (flops) versus stages of evolution is plotted in Figure 8 and Figure 9 respectively. Figure 10 shows the radiation pattern of the array in the ϕ=90 plane using (C5) and after 288 evolution steps. It is observed that a SLL of approximately -20dB is achieved for the linear array. This shows the effectiveness of the design with an improvement of more than 6.5dB over the best possible SLL for a uniform linear array which is well known to be -13.5 dB's.

As a sample, Table 2 shows the results of the design in problem #3. The position (relative to the center of the array) in terms of wavelengths, amplitude and phase (in degrees) of each element of the linear array in problem #3 is presented in Table 2.

6. CONCLUSION

To improve the radiation pattern and the array

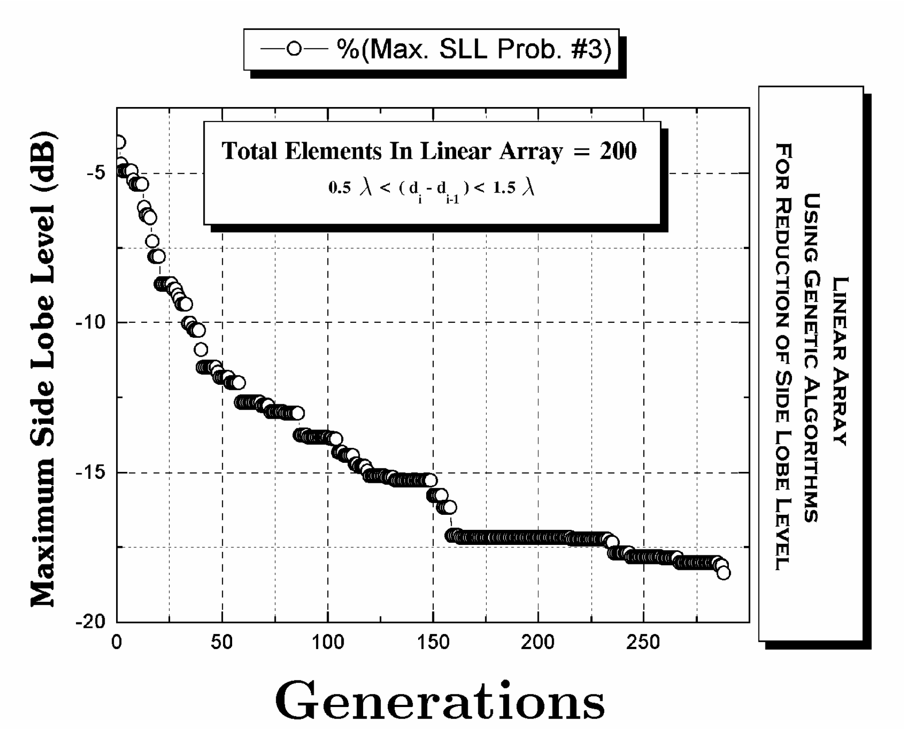

Figure 8. Maximum SLL (dB) of a linear array versus stages of evolution in the modified

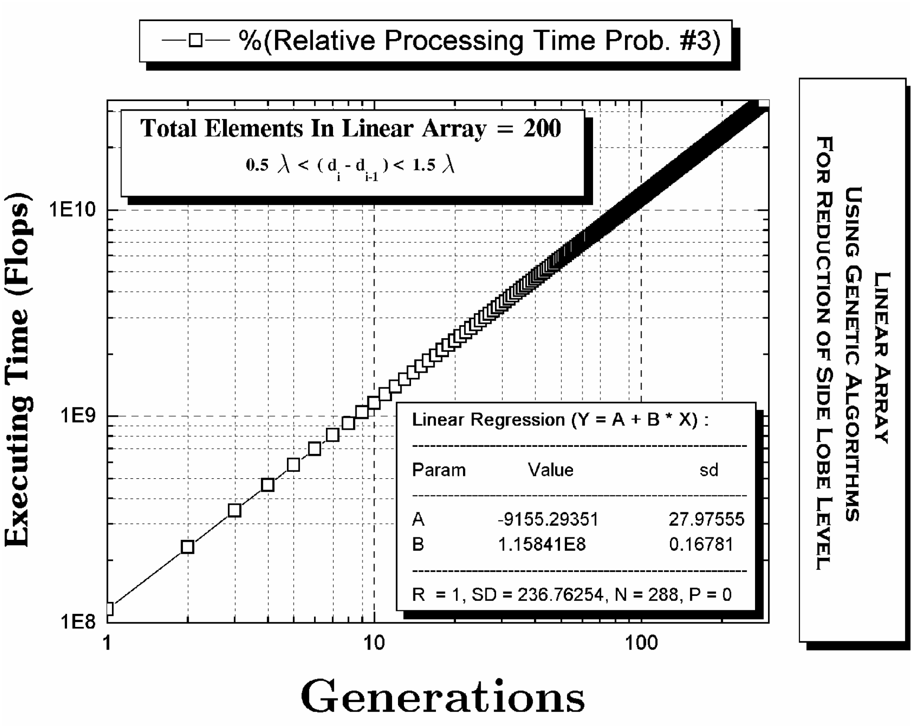

Figure 9. Execution time versus stages of evolution in the modified continuous GA (C5).

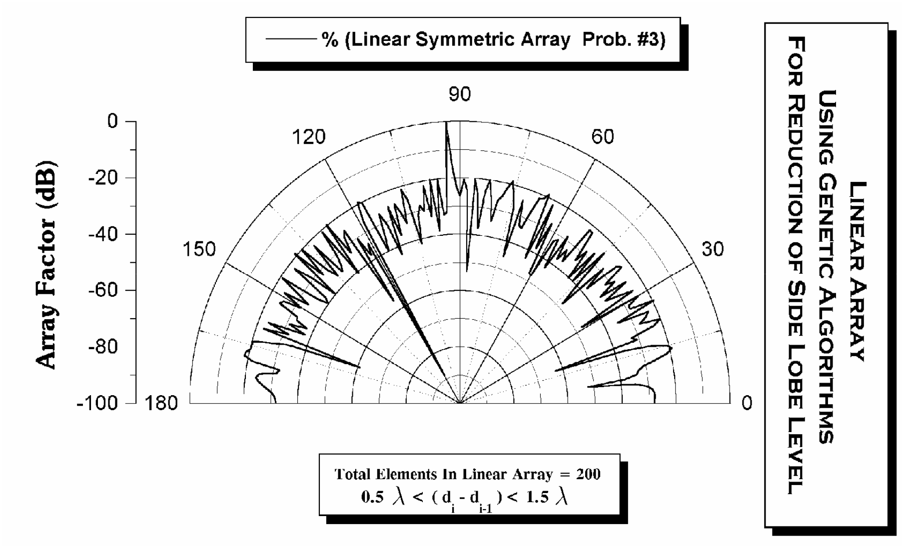

Figure 10. The radiation pattern of the array in problem #3 using modified continuous GA (C5) with 288 evolution stages.

TABLE 2. Positions of Elements from the Center of the Array (in Wavelengths), Relative Amplitudes and Phases for Problem #3.

No.	Position	Amplitude	Phase	No.	Position	Amplitude	Phase
1	0.833	0.5742	105.8	51	50.6	0.8887	264.4
2	1.962	0.9904	173.8	52	51.95	0.5955	241.7
3	3.257	0.7943	232.1	53	52.71	0.1169	271.8
4	4.157	0.2715	267.4	54	53.96	0.5743	317.5
5	5.07	0.9405	241.8	55	55.03	0.8535	296.1
6	6.077	0.9153	236.7	56	55.56	0.0412	232.4
7	6.864	0.5936	273.6	57	56.58	0.6835	333.6
8	7.549	0.2928	216.1	58	57.97	0.02812	224
9	8.368	0.7989	219.1	59	58.54	0.7085	359.1
10	9.564	0.878	230.7	60	59.36	0.439	352.6
11	10.92	0.5115	297.6	61	60.14	0.3052	17.02
12	12.25	0.9551	296.9	62	60.95	0.8499	341.6
13	12.82	0.02764	353.7	63	61.64	0.4154	358.9
14	13.96	0.7791	298.4	64	62.89	0.8658	25.1
15	15.19	0.8446	317	65	64.11	0.6956	10.96
16	16.12	0.3918	298.5	66	64.67	0.1315	305.6
17	16.94	0.9108	14.06	67	65.26	0.4182	99.7
18	18.04	0.2225	335	68	66.47	0.8399	35.37
19	19.22	0.9637	9.1	69	67.87	0.9815	67.04
20	20.25	0.5685	45.13	70	69.22	0.9858	59.57
21	21	0.8842	307.9	71	70.14	0.4902	101.5
22	21.87	0.8766	22.08	72	71.16	0.2882	99.91
23	23.07	0.829	27.99	73	71.86	0.216	128.4
24	24.47	0.9895	35.68	74	73.03	0.3237	85.74
25	25.42	0.8268	110.5	75	74.13	0.1976	166.2
26	26.2	0.02656	280.6	76	75	0.3819	111.1
27	26.8	0.9525	69.18	77	76.07	0.8542	120.2
28	27.88	0.8221	129.4	78	77.29	0.7726	179
29	28.51	0.7664	47.65	79	78.71	0.5502	154.2
30	29.55	0.6424	100.7	80	80.14	0.2991	172.5
31	30.25	0.5463	28.89	81	81.17	0.1071	255
32	31.17	0.7808	81.41	82	82.12	0.5199	207.8
33	32.41	0.9887	126.7	83	82.96	0.03923	305.3
34	33.57	0.6375	134.2	84	83.76	0.8816	174.5
35	34.78	0.1638	163	85	84.88	0.3496	280.8
36	36.24	0.9275	163.2	86	85.49	0.2936	39.32
37	37.5	0.9966	150.5	87	86.5	0.1564	318.7
38	38.56	0.03113	175.4	88	87.38	0.2567	259.7
39	39.12	0.471	149.8	89	88.38	0.2931	263.85
40	39.74	0.2277	203.5	90	89.35	0.152	21.87
41	40.43	0.5353	81.44	91	90.08	0.9536	230.7
42	41.44	0.9417	179.1	92	91.08	0.2066	8.721
43	42.72	0.9182	202.8	93	91.7	0.6377	278
44	43.8	0.4626	196.7	94	92.77	0.8995	288.2
45	44.85	0.9387	230.5	95	93.78	0.1132	297.5
46	45.83	0.2763	204.5	96	94.9	0.9972	304.5
47	46.6	0.8465	247	97	96.1	0.9267	328.9
48	47.53	0.2209	267.9	98	97.54	0.3928	29.65
49	48.79	0.2746	238.8	99	98.3	0.3594	208.5
50	49.51	0.5467	313	100	99.1	0.6393	329

factor, a combination of array variables (positions, amplitudes and phases) was controlled in such a way that an increase in the dimension of the problem, and independent of the continuous GA method, the convergence of the problem is still possible. In continuous GA, the required processing time increases linearly with an increase in the dimension of the problem while the convergence time for the response increases logarithmically [10]. Two problems with dimensions 72 and 192 were analyzed using several proposed modified GA algorithms and the results as well as the convergence rate is presented as several plots. The effectiveness of the proposed modified versions were studied and compared. With the selection of a complicated problem having a dimension of 300, the results, convergence time, and the variation of convergence versus evolution stages were obtained and were given in several plots. With an increase in the dimension of the problem and without a drastic increase in the computational time modified continuous GA versions make it possible to find an optimized solution fairly close to a global optimum.

7. ACKNOWLEGMENT

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