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Genetic Algorithm for the Design of Phase distribution to Reduce Quantization Lobes

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Abstract

In phased arrays, quantization lobes appear most often even without phase. However, it is possible to reduce them by optimal design of phase distribution. Keeping phase distribution fact in view, Genetic Algorithm is used to design suitable phase distribution which could reduce quantization lobes. A linear array is considered in the present work. The optimized phase obtained with genetic algorithm, resulted in the reduction of unwanted lobes by 7–8 dB. These results are useful for radar applications. The patterns are numerically computed for large and small array and are presented in u (sin θ) domain.

Keywords

Quantization lobes, Radiation pattern, Genetic Algorithm.

1. Introduction

Line source is defined as a continuous distribution of current along a line segment [1]. It is obvious that the continuous line source doesn't exist in practice and it is only of theoretical significance. The continuous line source can be considered to be a discrete array with infinite number of radiating elements over a finite length with no spacing between them. Design of a line source is nothing but generation of excitation distribution to obtain the desired pattern. This distribution can be applied to any physical linear antenna array for practical applications to get the desired pattern.

Modern communications and radar systems need high performance antennas to cope with electromagnetic interference. These antennas are required to produce narrow beams and low side lobes. In addition, these antennas must reduce unwanted signals entering in to the main beam, side lobes and also quantization lobes. In an array of identical radiating elements, overall pattern can be obtained by varying amplitude level, phase level and space distribution of elements.

Low sidelobes can be obtained through carefully amplitude weighting the signals received at each element [2-3]. An alternative for obtaining low side lobes is space tapering [4]. Space tapering produces the low-side lobe level by making the element density propositional to the desired amplitude taper at a particular location on the array [5].

Taylor developed a method to optimize the side lobe levels and beamwidth of a line source [6]. R. S. Elliot extended Taylor's work to new horizons, including Taylor based tapers with asymmetric side lobe levels, arbitrarily side lobe level designs [7].

The phase control approach can be precisely used to produce sector beams. It is useful for both scan and non-scan applications. In defense radars, there exist several situations where beam shapes are required to be altered in quick succession. This is possible only by phase control for a fixed amplitude distribution. Such requirements can be met by phased array antennas where the phase distribution has a full control on the radiation beams [8-9]. GA can be used for optimization of phase distribution and hence controlling the radiation pattern using optimized phase.

In this paper, Genetic Algorithm (GA) is proposed to optimize the element excitation phase distribution. The generated phase distribution is used, without varying the amplitude element excitation distribution, to obtain the desired radiation pattern.

Genetic Algorithm is evolutionary technique mostly used in electromagnetics. Although (GA) started much earlier than 1975, Holland introduced its literature and it is applied to many practical problems by Goldberg [10].

Optimization of radiation pattern of an array to reduce sidelobe levels and quantization lobe levels are studied in the literature [11-14] using genetic algorithm (GA). GA is used to optimize the radiation pattern of different geometries and physical structure of antennas. The parameters used for optimization is element spacing, amplitude weights and element geometry to achieve required radiation pattern constraints. But this optimization technique using above parameters is subject to the case of study.

GA is used in design of thinned array of large number of elements in [15-16]. The parameters used for optimization is switching ON-OFF the elements of the array to obtain required radiation pattern. Sidelobe levels and mainlobe direction are considerably attained by this technique.

Genetic Algorithm

Genetic algorithms are based on the mechanics of natural selection and natural genetics. A genetic algorithm is a search technique used in computing to find exact or approximate solutions to optimization and search problems. The main theme of research on genetic algorithm has been robustness, the balance between efficiency and efficacy necessary for survival in many different environments.

Genetic algorithm is a powerful optimization method in the synthesis of desired patterns with reduction of quantization lobes. The genetic algorithm is a method for solving both constrained and unconstrained optimization problems. Here GA is used to generate random phases to add to the element excitation function for reduction of quantization lobes and also side lobes.

A step by step procedure is given for explaining how optimum phase excitations can be obtained using GA.

First step is to define the fitness function for the given problem. Define the parameters which are to be optimized using GA. In present case, phase values are parameters and to optimize the radiation pattern of 20 element linear array with reduced sidelobe levels.

Initialize all the population with uniformly distributed random values. For phase optimization of 20 element linear array requires, 20 parameters (phase values) to be optimized. So each individual in the population has 20 parameters. The individual parameters are called chromosomes. So in this step an initial population of M*N size is taken implies 'M' individuals are generated with 'N' chromosomes each.

Next step is to evaluate the population for finding the best chromosomes using a fitness function.

$$\text{Fitness} = PSLL_o - PSLL_D$$

Where

$$PSLL_o = \text{Max}\left[20\log\left(\frac{E(u)}{E_{max}}\right)\right] \qquad u_o \le u \le 1 \qquad 1$$

$$PSLL_D = \text{Desired sidelobe level.}$$

u_o = Position of first sidelobe level in u - domain

E_{max} = Main beam peak level.

The flow chart shown in Fig. 1 outlines the GA technique

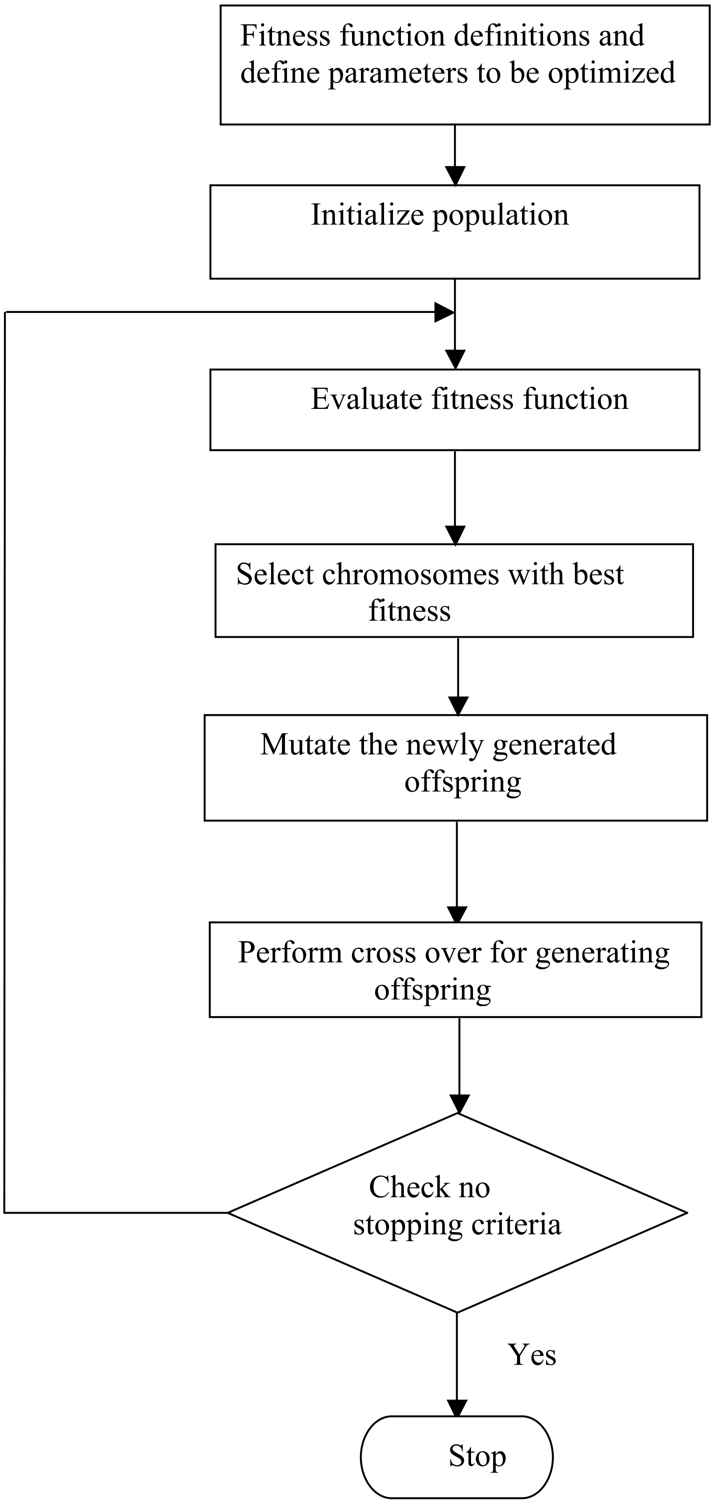

Fig. 1 Genetic Algorithm Flowchart

Here, each individual is assigned a fitness value. All the individuals are then arranged in the order of best fitness value. Fitness represents the goodness of an individual.

In selection process the chromosomes with a fitness value above a threshold are selected as parent chromosomes for generating offspring. There are different types of selection. Simple method is to assign ranks to the chromosomes based on their fitness. Choose a cut-off value, remove all the population with fitness below that value and the remaining chromosomes act as parents for generating offspring.

The generation of new chromosomes using two processes namely crossover and mutation. In crossover, two parent chromosomes are taken at a time to produce two children. There are different crossover methods in use. The objective of crossover is to produce more fit individuals by combination of best parent chromosomes.

The Mutation is mainly performed to avoid stucking at local optimum solutions of a given problem. It randomly replaces chromosomes in randomly selected individuals with a random value.

The final step is to check the convergence. For this, different criteria can be used. Criterion like finishing of maximum number of iterations or attaining of a present fit value or reaching of set time is some examples. If any of the criteria is satisfied, the algorithm stops. This step is also crucial in finding the global optimum. At the end, the chromosome with best fitness value, after reaching the stopping criteria becomes the global optimum.

2. Formulation

Line source is defined as a continuous distribution of current along a line segment. A typical line source and its Geometry is shown in Fig. 2

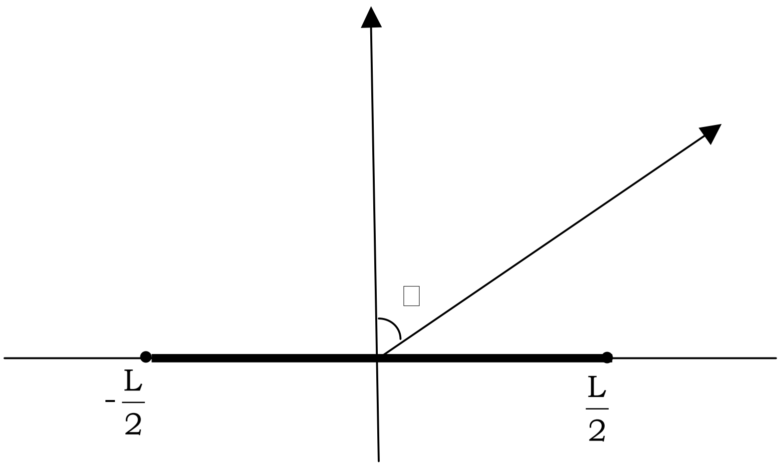

Fig. 2: Geometry of a Line source

The far-field of line source appears in the form of radiation integral and it is given by

$$E(u) = \int_{-1}^{1} A(x)\, e^{j\frac{2\pi L}{\lambda}[ux+\phi(x)]}\, dx \qquad 2$$

Here,

$A(x)$ = Amplitude excitation

$\frac{2L}{\lambda}$ = Normalized array length

i.e. it is normalized with respect to λ, hence there are no units.

'x' is a variable point on the line source. This is normalized to have its length from -1 to +1.

$\phi(x)$ = Phase Distribution

$u = \sin\theta$, θ is the angle from boresite to the direction of observer

The above equation (2) represents the field pattern for continuous line source.

3. Proposed amplitude and phase distributions

The fixed amplitude and element excitation phase distributions are shown in figs (3-4). By using these distributions to achieve the desired radiation pattern.GA based approach is implemented for optimized phase distribution.

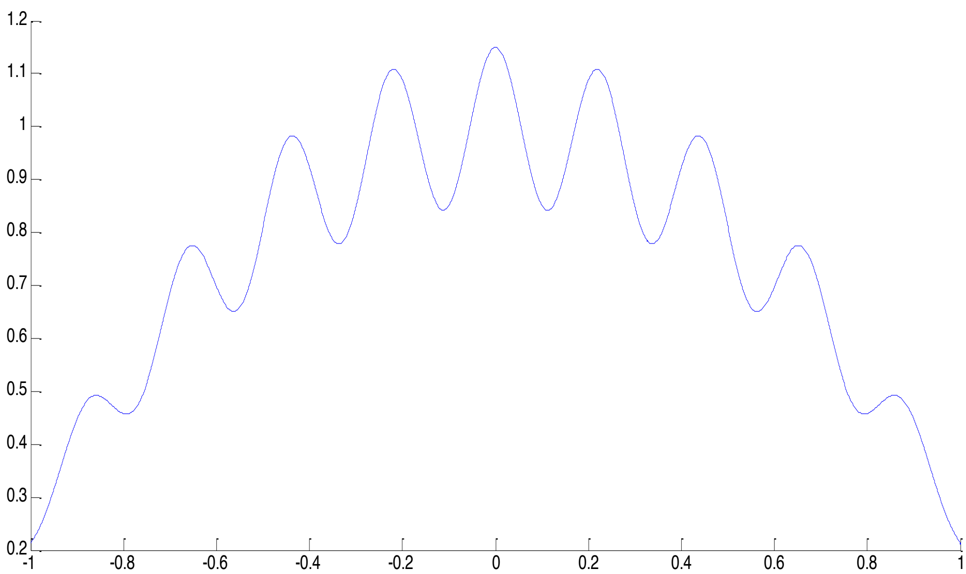

Fig. 3: Amplitude Distribution using Cosinusoidal Amplitude Modulation

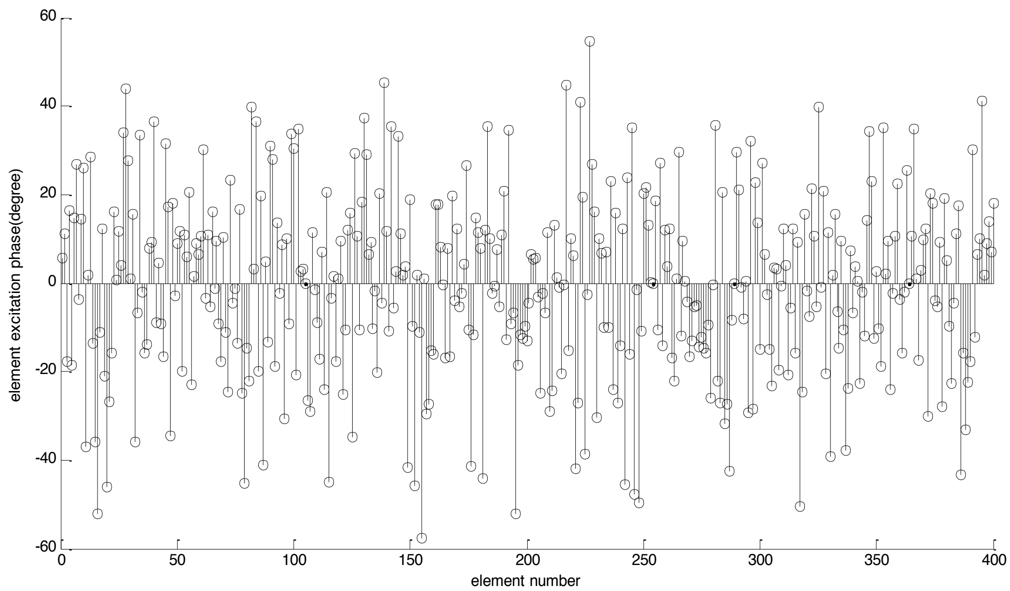

Fig. 4: Element excitation phase distribution

4. Results

In the present work, optimized phase using GA has been considered for the line sources of different lengths. The amplitude distribution generated by cosinusoidal amplitude modulation is considered and is kept fixed for all array lengths. The amplitude and phase distributions that are considered in the present work are presented in Figs (3-4). The resultant radiation patterns of array length 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 are shown in Figs (5-14). Patterns without phase optimization were also included in each Figure for clarity purpose. The analytical data of the above radiation patterns are tabulated in Table-1 for easy comparison. The reduction of quantization lobes and sidelobes by adding phase generated by GA can be observed and compared using below Table.

Table. I shows the first sidelobe level, second side lobe level, Quantization lobe level and beam width of radiation pattern of different array lengths without and with phase optimized by GA. It is observed that the quantization lobe level is reduced considerably of 7-8 dB with slight, negligible variation in first and second sidelobe levels.

		A(X)				A(X) + ϕ(X)			
S.NO	2L/λ	QLL	1ST SLL	2nd SLL	B.W	QLL	1ST SLL	2nd SLL	B.W
1.	10	-21.8	-19.67	-25.65	0.2568	-28.35	-19.05	-25.77	0.2526
2.	20	-21.8	-19.67	-25.66	0.1283	-28.38	-19.11	-25.80	0.1202
3.	30	-21.8	-19.67	-25.66	0.082	-28.38	-19.05	-25.99	0.08
4.	40	-21.8	-19.67	-25.66	0.064	-28.42	-19.11	-25.80	0.06
5.	50	-21.8	-19.67	-25.67	0.05	-28.42	-19.21	-25.85	0.05
6.	60	-21.82	-19.7	-25.66	0.044	-28.42	-19.26	-25.99	0.04
7.	70	-21.82	-19.72	-25.69	0.038	-28.42	-19.26	-26.17	0.04
8.	80	-21.82	-19.72	-25.66	0.032	-28.44	-19.22	-26.17	0.03
9.	90	-21.81	-19.7	-25.68	0.026	-29.02	-19.26	-26.42	0.03
10.	100	-21.82	-19.78	-25.70	0.026	-29.32	-19.36	-26.67	0.03

Table. 1 Comparison of sidelobes and beam width for GA optimization.

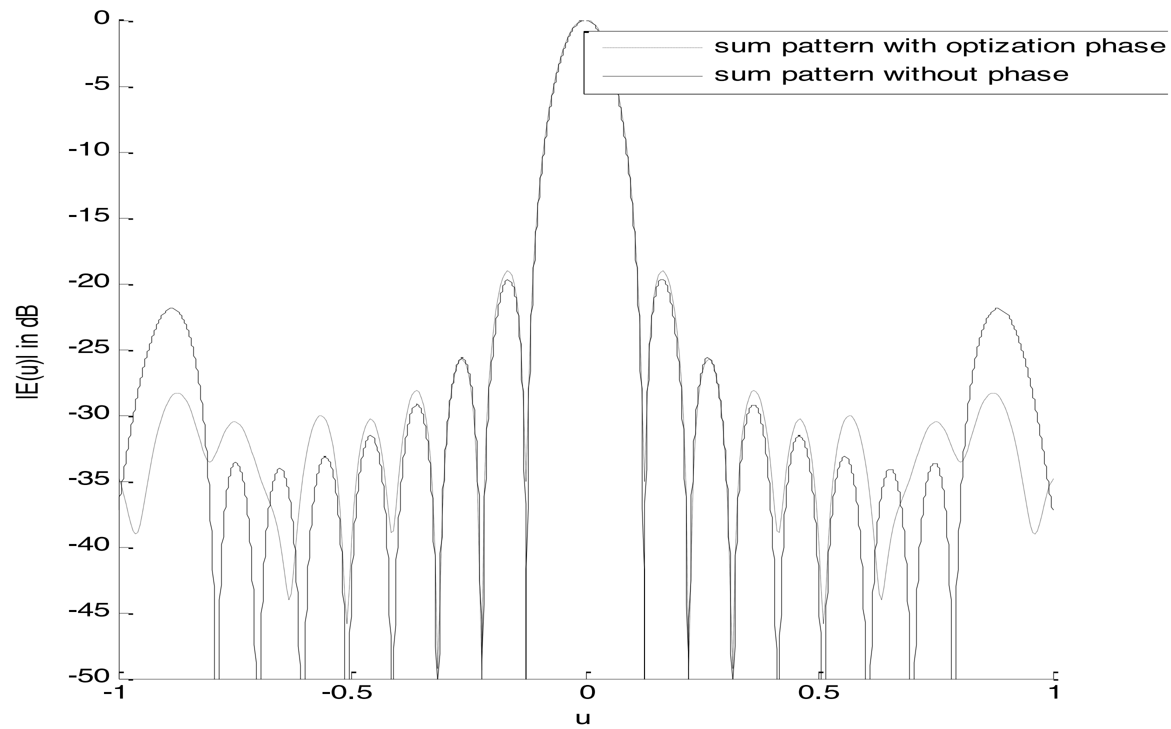

Fig.4.Radiation pattern with reduced quantization lobes using optimization phase for 2L/λ=10

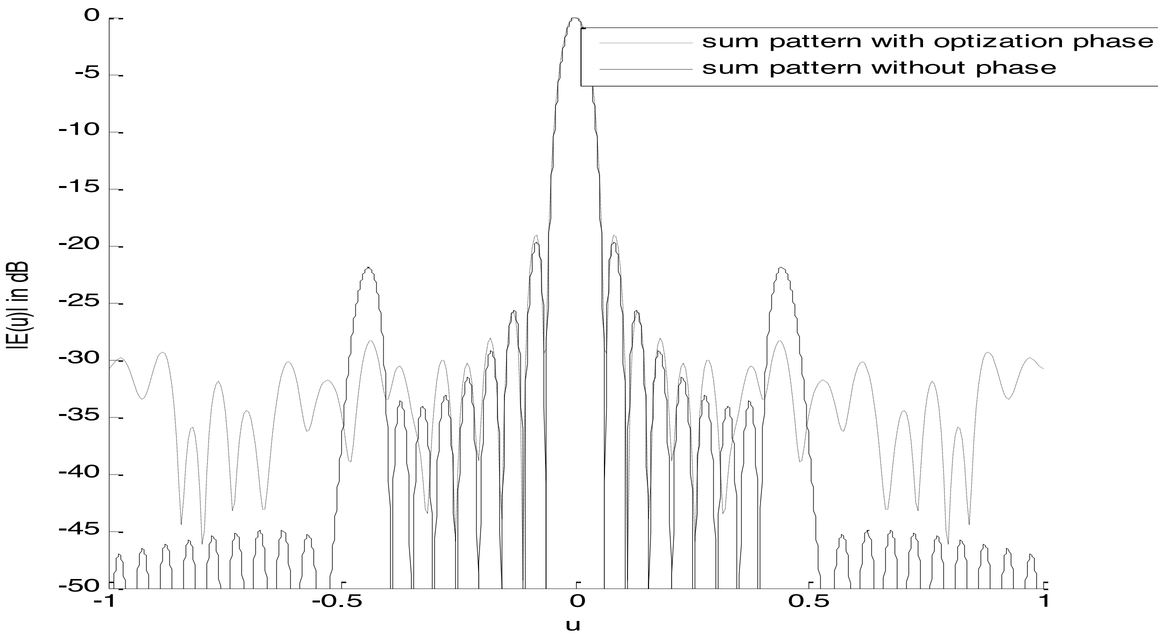

Fig. 5. Radiation pattern with reduced quantization lobes using optimization phase for 2L/λ=20

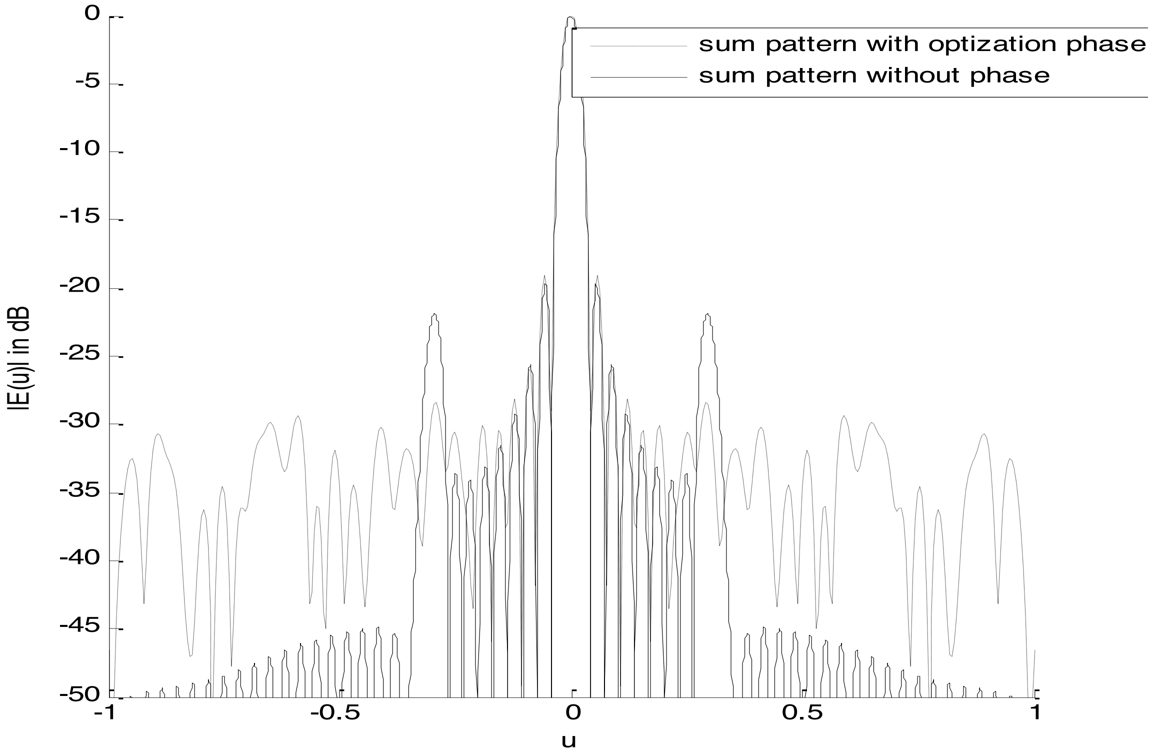

Fig.6. Radiation pattern with reduced quantization lobes using optimization phase for 2L/λ=30

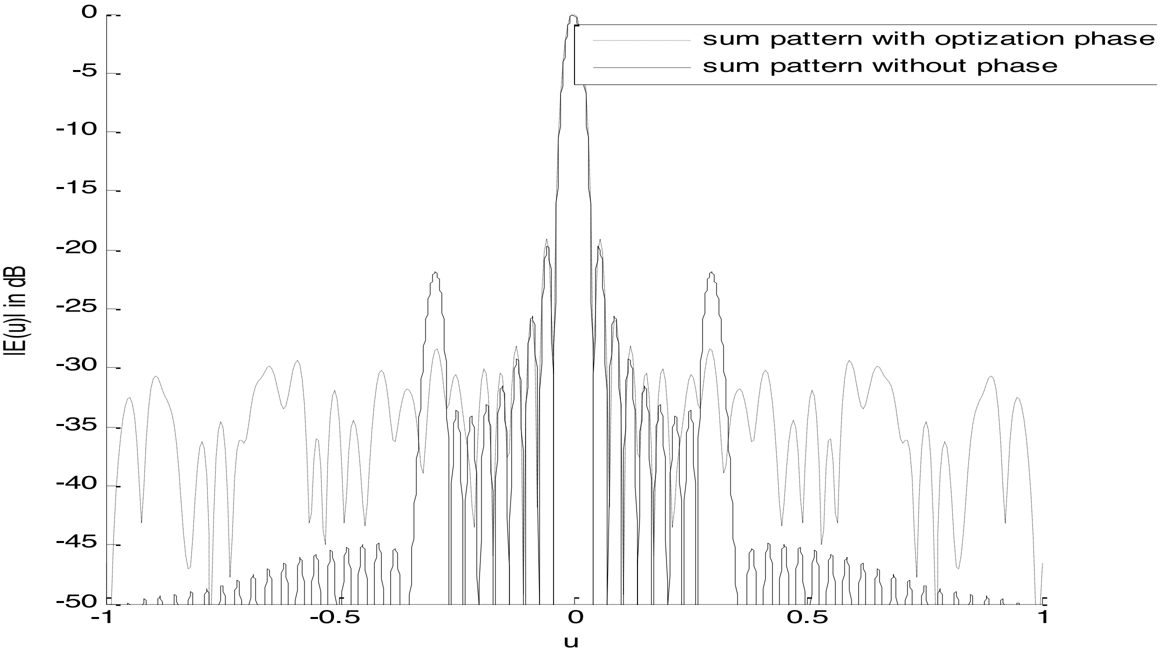

Fig.7.Radiation pattern with reduced quantization lobes using optimization phase for 2L/λ=40

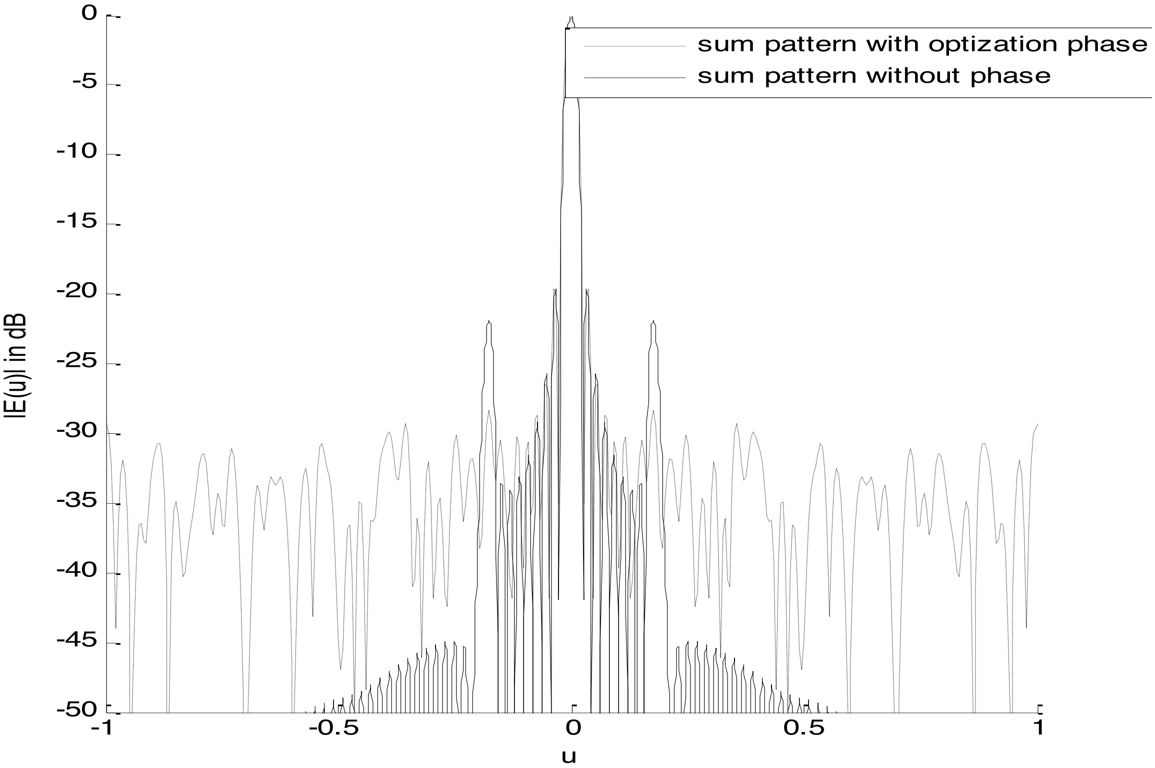

Fig.9.Radiation pattern with reduced quantization lobes using optimization phase for 2L/λ=60

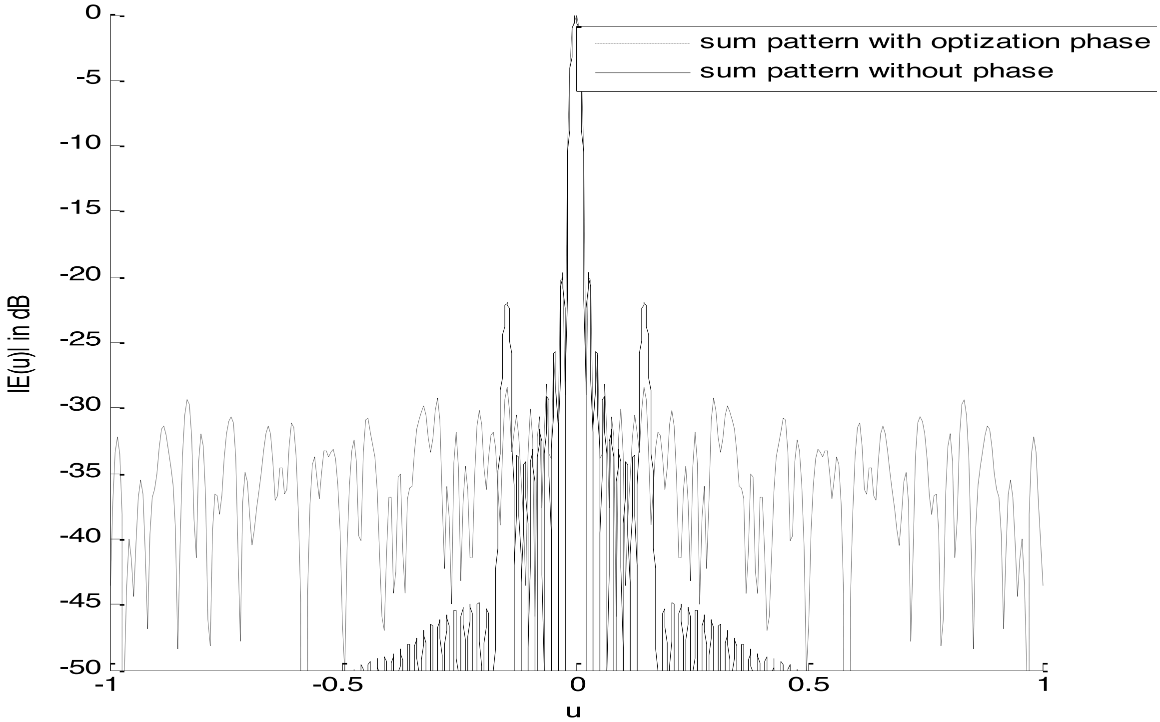

Fig.9.Radiation pattern with reduced quantization lobes using optimization phase for 2L/λ=60

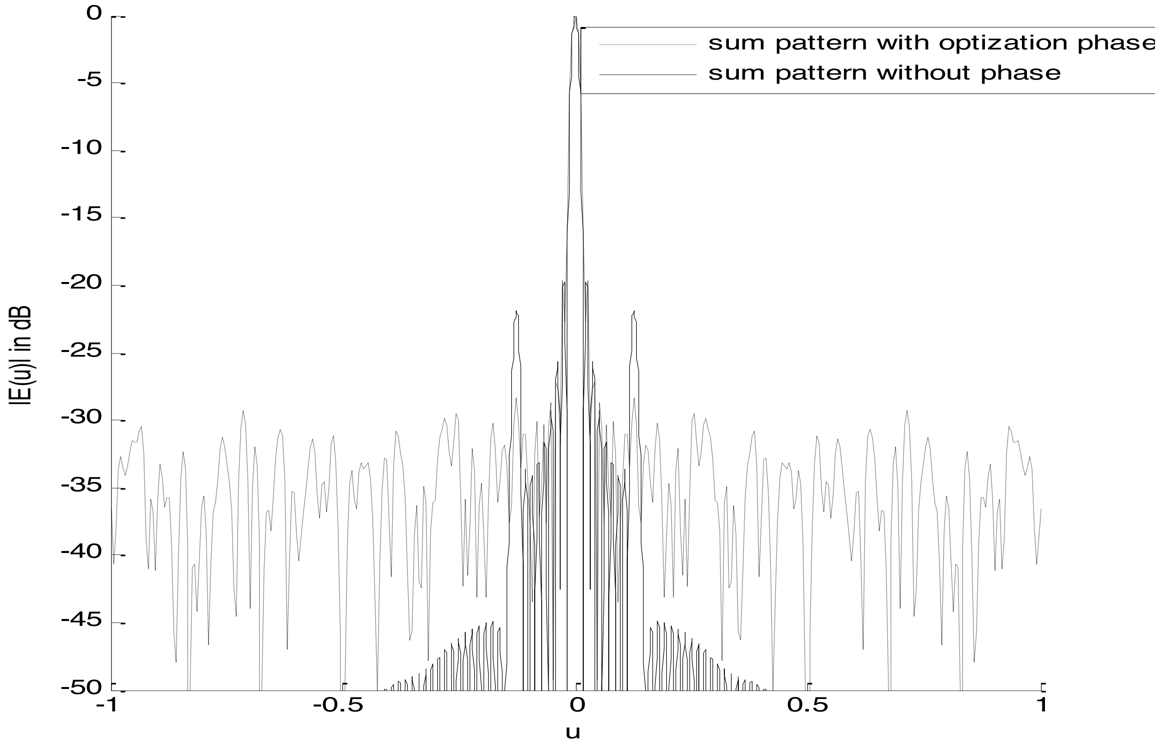

Fig.10.Radiation pattern with reduced quantization lobes using optimization phase for 2L/λ=70

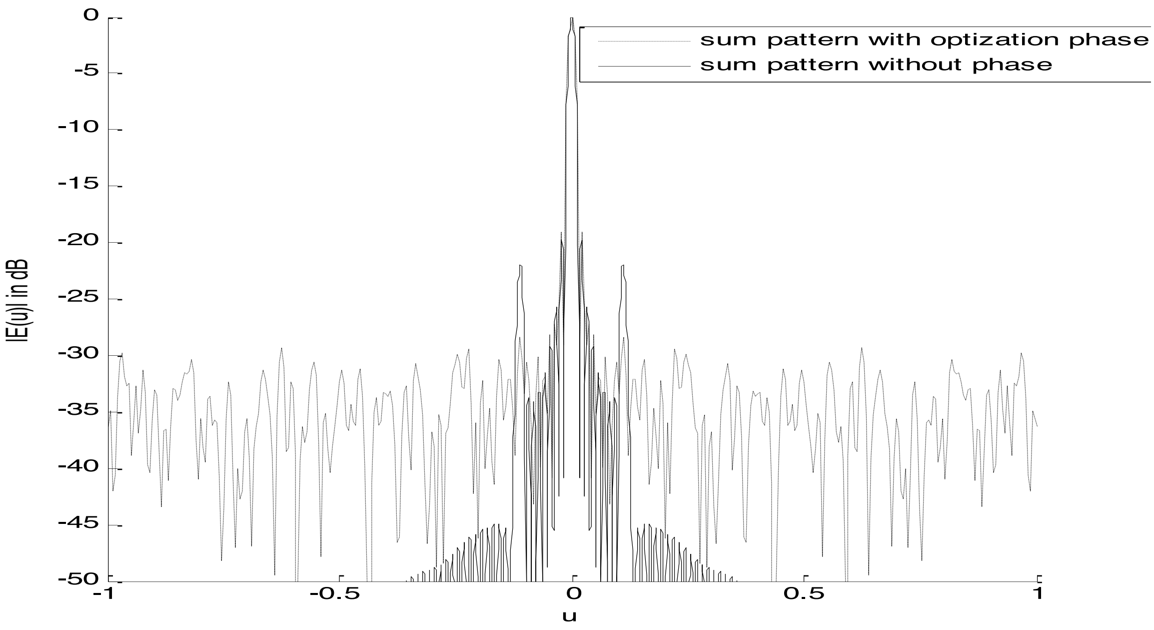

Fig.11.Radiation pattern with reduced quantization lobes using optimization phase for 2L/λ=80.

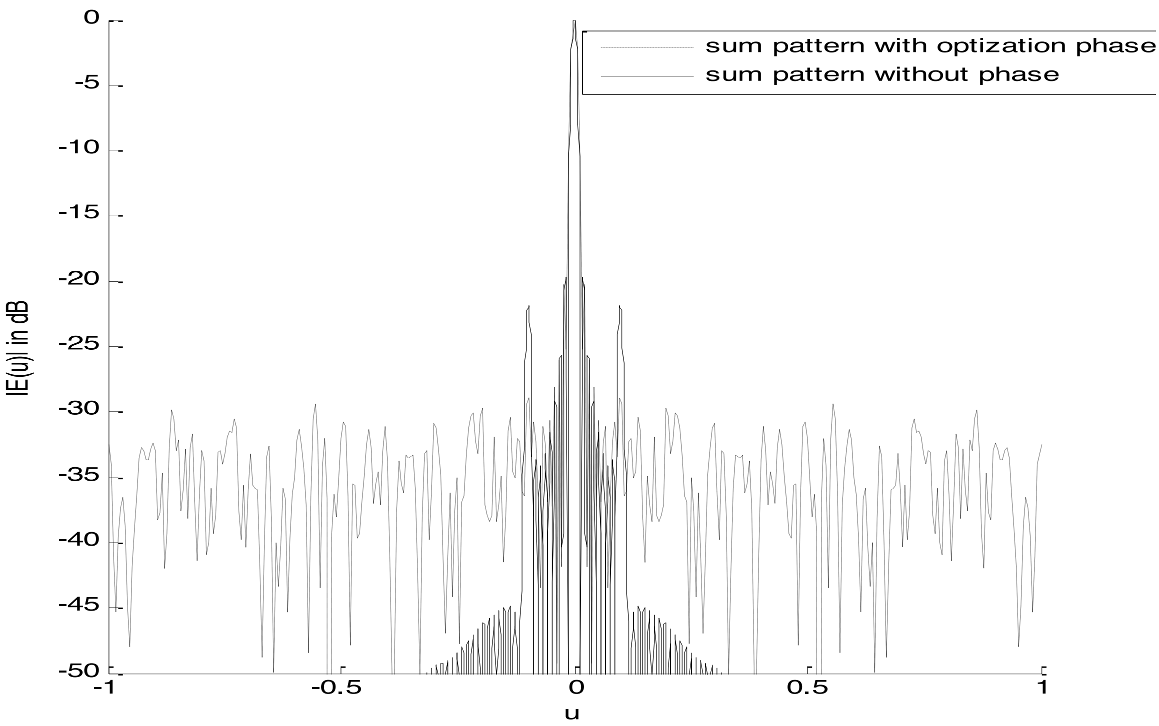

Fig.12.Radiation pattern with reduced quantization lobes using optimization phase for 2L/λ=90.

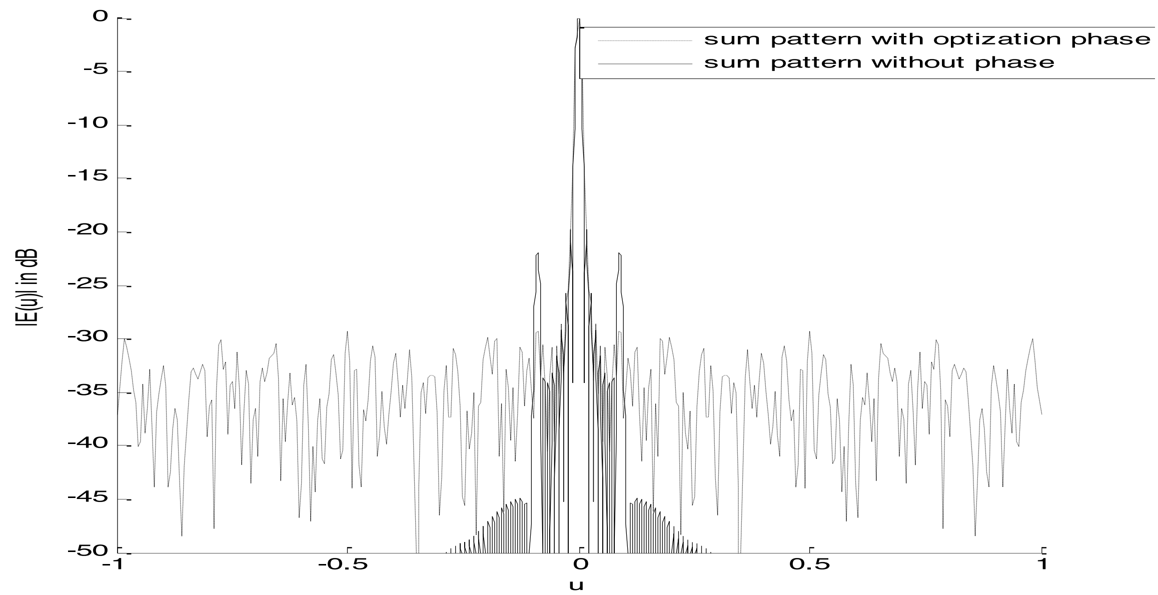

Fig.13.Radiation pattern with reduced quantization lobes using optimization phase for 2L/λ= 100

5. Conclusions

It is found from the results of Figs. 5-14, the quantization lobes appears at -22dB. By introducing the phase distribution of Fig. 4 designed by Genetic Algorithm, it has been probable to reduce it to -29dB as evident from the same Figs. 5-14. By increasing array length, the beam width of the main beam remains unaltered while reducing the quantization lobe level. Hence, this technique is useful for radar applications.

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