Design of Thinned Linear Antenna Array using Particle Swarm Optimization (PSO) Algorithm

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***Abstract* — This paper describes the unwanted side lobe level reduction of thinned linear array antenna using particle swarm optimization (PSO) algorithm. In RADAR and satellite communication, very low side lobe level is required. The purpose of this paper is to reduce side lobe level of linear antenna array using optimization technique. Thinning of an antenna array involves switching 'ON' some antenna elements and rest all the elements are switched 'OFF'. Turning 'OFF' some of the antenna elements do not degrade the system performance. The investigations presented in this paper may be useful for Direct Broadcast Satellite (DBS) systems.**

Keywords -- array factor; linear antenna array; particle swarm optimization; side-lobe level.

I. INTRODUCTION

In satellite communication, DBS system plays an important role, where the signals can be directly delivered to subscribers from geostationary satellite [1]. Widely used direct-to-home (DTH) satellite system, used for home TV reception is an example of a DBS system. Direct Broadcast Satellite (DBS) system requires the antenna with very high gain. The thinning process involves strategically ON and OFF some antenna elements [2, 3] to achieve almost similar radiation pattern like fully populated array with low power energy consumption. In Fig 1. Fully populated array and thinned array are shown.

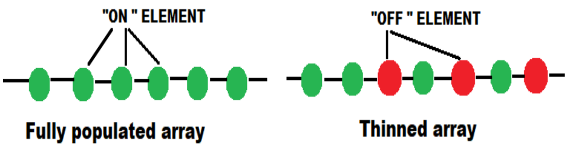

Figure1. Fully populated array where all the elements are ON and thinned array where some of the elements are in OFF state.

In fully populated array, due to the turning ON of all the antenna elements (or state 1), as a result, cost, weight and the power consumption is gradually increased. In a large antenna array, the use of digital beam-former can be reduced in a DBS system by switching 'OFF' (or state 0) some of the antenna elements and side lobe levels are also reduced which does not affect the system performance. Among the various thinning methods, the most popular technique for array thinning is the Optimization. It can be used for various types of arrays including linear, elliptical array, planar, circular array etc. [4, 5, 6]. Differential evolution, genetic algorithm are already used for the optimization of array thinning. But PSO and its variants are not yet widely used for array thinning.

In this paper, Particle Swarm Optimization (PSO) technique is used for array thinning. Simulation is performed with the help of MATLAB. 15 and 20 elements linear antenna array with various population sizes is considered for array thinning where numerical results shows that the lowest side lobe is obtained using this method.

II. PARTICLE SWARM OPTIMIZATION

Particle swarm optimization (PSO) is a population based stochastic optimization technique inspired by the social behaviour of bird flocking or fish schooling. The basic PSO algorithm is shown in Figure.2.

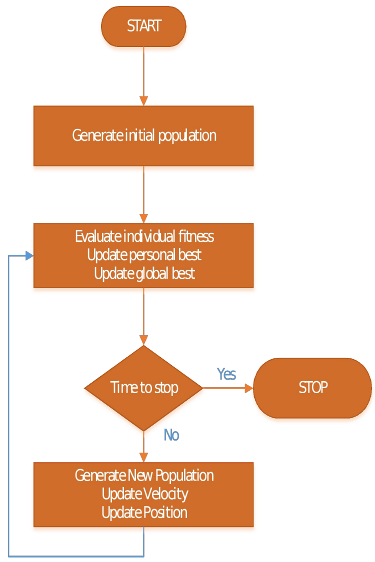

Figure2. Flowchart of PSO

Particle swarm optimization was introduced by Eberhart and Kennedy, so many scientific research papers have been developed. Particle Swarm Optimization (PSO) is a swarm intelligence meta-heuristic process which is inspired by the group behaviour of the flock of birds or schools of fishes [7, 8]. It is a population based method which shows the algorithm state by a size of population, which is updated every generation until the stopping criterion is satisfied [9, 10].

Solving an optimization problem is the main motivation of PSO, the fitness function can be considered as f: R_d□ R. The population P= {q_1, q_2…, q_n} of the solutions are called a 'swarm'. The feasible solutions $q_1,q_2…,q_n$ are the particles. PSO keeps the same population size which is not varying from generations to generations, iteratively updating the positions of the particles.

The first, second and third part of the velocity formula is called inertia, cognitive component and the social neighbourhood component respectively which is shown below,

$$K_i(t+1) = M(t)N_i(t) + \phi_1 u_1 (P_i(t) - Q_i(t)) + \phi_2 u_2 (L_i(t) - Q_i(t))$$

The symbols u_1 and u_2 are the random variables with z(0,1) distribution.

Position of particle i changes according to,

$$Q_i(t+1) = Q_i(t) + K_i(t+1)$$

Where,

$Q_i(t)$= Position of a d-dimensional vector

$P_i(t)$= Historically best position

$L_i(t)$= Historically best position of the neighbouring particles.

$K_i(t)$= Speed of the particles and it is the step size between $X_i(t)$ and $X_i(t+1)$.

The positions of the particles are randomly initialized at the beginning, and the velocities are set to 0, or to small randomly taken values. There are few parameters in PSO where M(t) is the inertia weight, a damping factor which usually decreasing from 0.9 to around 0.4 and ϕ_1, ϕ_2 are the acceleration coefficients and these are usually in between 0 and 4 [12, 13]. The algorithm is terminated if once the fitness values of the particles are achieved after a given number of iterations.

III. ARRAY THINNINGUSING PSO FOR LINEAR ARRAY

Considering a set of 'N' elements linear antenna array (Figure 3)

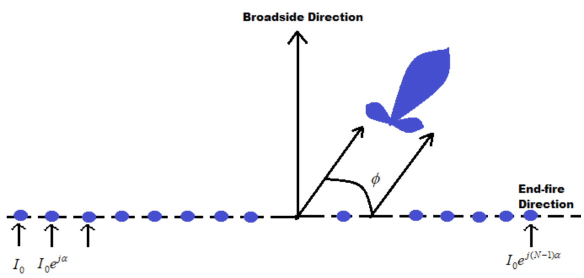

Figure 3. Linear antenna array with fixed inter-element spacing 'd'.

The equation for the Array Factor (AF) at scanning angle ϕ can be represented as,

$$AF = \sum_{n=1}^{N} In.e^{j(n-1)\beta d(\cos\theta - \cos\phi)}$$

Where, β= 2π/λ,

λ= Wavelength,

α = Progressive phase shift between elements.

Hence the cost function to be optimize is,

$$SLL_{\max} = \max \left| \frac{AF(\theta)}{\max(AF)} \right| \theta = \theta_{SLM}$$

Where,

$$\theta_{SLM} = 0^\circ \le \theta \le (\phi - p) \cup (\phi + q) \ge \theta \ge 180^\circ$$

p = First left null point to main beam at scanning angle ϕ.

q = First right null point to main beam at scanning angle ϕ.

IV. SIMULATED RESULTS

Design consideration of thinned array utilizes only two fixed values, for 'on' state current amplitude is '1' and 'off' state current amplitude is '0'. Among various optimization techniques, PSO is programmed using MATLAB to minimize the maximum side-lobe level. Optimization technique uses the cost function, 15 and 20 elements linear antenna array with inter element spacing d=0.4λ. Number of iterations or generations=200.

A. For 15 Elements Linear Antenna Array

Now, for 15 elements, the optimal plot of normalized array factor is shown in Figure 4. Inter element spacing, d=0.4λ and 50 iterations. For fully populated array when d=0.4λ, maximum side lobe level (SLL_{max}) is
-13.1 dB, FNBW=20 degree.

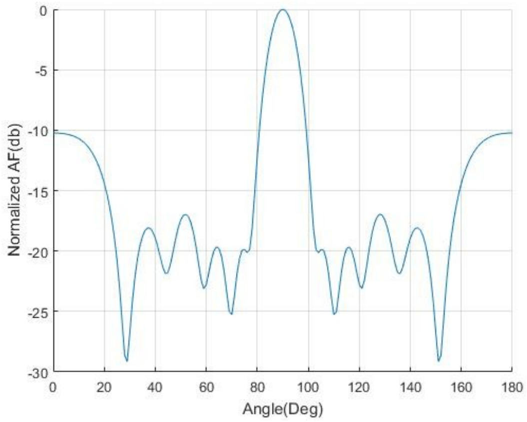

Figure 4. Optimal plot for the reduced SLL for N=15, population size=60

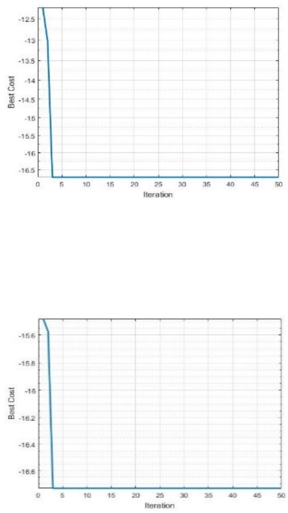

Figure 5(a). Best plot for reduced SLL for N=15 and d=0.4λ, population size=60. (b) Best plot for reduced SLL for N=15 and d=0.4λ, population size=150.

From the results tabulated in Table 1 below, a successful conclusion can be drawn that side lobe levels are reduced for various population sizes which is almost 3.8dB without changing the major characteristics of the main beam.

TABLE 1: SIMULATED RESULTS FOR N=15 ELEMENTS LINEAR ARRAY ANTENNA WITH MAXIMUM ITERATION=50AND VARIOUS POPULATION SIZES.

Population sizes	On/ Off elements	SLL_max (dB)	FNBW (Deg)
60	001011111110101	-16.9560	28
75	101111111010100	-16.9560	28
90	001011111110101	-16.9560	28
105	001011111110101	-16.9560	28
120	001011111110101	-16.9560	28
135	001011111110101	-16.9560	28
150	010101111111010	-16.9560	28

B. For 20 Elements Linear Antenna Array

Now, for 20 elements, d=0.4λ and 50 iterations, the optimal plot of normalized array factor is shown in Figure 6.
For fully populated array when d=0.4λ, maximum side lobe level (SLL_{max})= -13.3dB, FNBW=14 degree

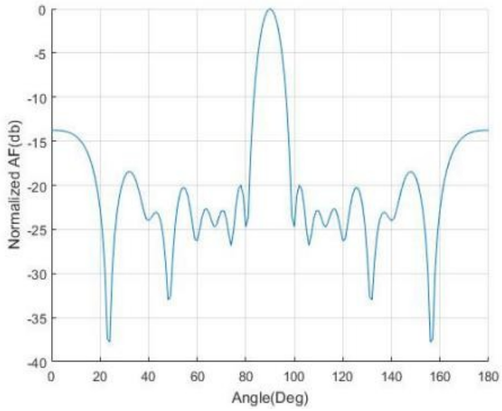

Figure 6. Optimal plot for the reduced SLL for N=20

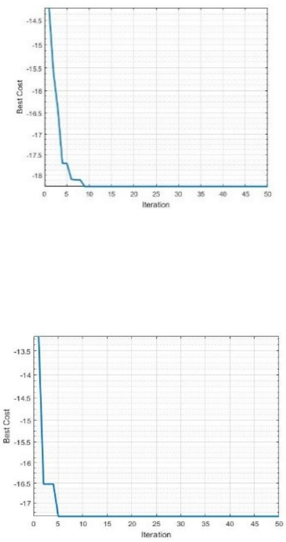

Figure 7(a). Best plot for reduced SLL for N=20 and d=0.4λ, population size=80 (b) best plot for reduced SLL for N=20 and d=0.4λ, population size=200

Similarly for 20 elements, results which are tabulated in Table 2, a successful conclusion can be drawn that side lobe levels are reduced for various population sizes which is almost 5.1dB without changing the major characteristics of the main beam.

TABLE 2: SIMULATED RESULTS FOR 20 ELEMENTS LINEAR ARRAY ANTENNA WITH MAXIMUM ITERATION=50 AND VARIOUS POPULATION SIZES.

Population sizes	On/ Off elements	SLL_max (dB)	FNBW (Deg)
80	00101011111111111101	-18.4	20
100	10111111111110101010	-18.5	18
120	10111111111111010100	-18.4	20
140	00101011111111111101	-18.4	20
160	00101011111111111101	-18.4	20
180	10111111111111010100	-18.4	20
200	01010111111111010101	-17.5	20

CONCLUSION

Particle swarm optimization (PSO) technique is used to optimize the sidelobe level of the thinned linear array antenna with properly maintaining same radiation pattern like fully populated array. Here, inter element spacing between the antenna elements are considered to be 0.4λ to minimize the appearance of side lobes. Optimization for 15 and 20 elements linear array is done by using PSO. For 15 elements side lobe level is reduced by almost 3.8 dB (table 1) and for 20 elements side lobe level is reduced by 5.1 dB (table 2) compared to fully populated array. Finally, a successful conclusion is drawn that, the unwanted grating lobe levels which are the major cause of the distortion during the proper communication of DBS system, are minimized by maintaining the proper beam-width.

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