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DESIGN OF A LINEAR ARRAY OF HALF WAVE PARALLEL DIPOLES USING PARTICLE SWARM OPTIMIZATION

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Abstract—Particle Swarm Optimization (PSO) is a new, high performance evolutionary technique, which has recently been used for optimization problems in antennas and electromagnetics. It has been used for optimization of linear array of isotropic radiators, and found to give better results than other companion algorithms. A half wave dipole is a practical radiator, which closely resembles the behavior of an isotropic radiator and is most common array element. In this paper, a linear array of half wavelength parallel dipoles has been optimized for minimum side lobe level and null control using Particle Swarm Optimization. The results obtained show superiority of PSO over conventional method.

1. INTRODUCTION

Antenna array synthesis consists of finding the complex excitation or physical layout of the array that produce the radiation pattern as close as possible to the desired one. For antenna array synthesis, many methods are available that use either variation of complex excitations, i.e., of amplitude and phase or variation of element spicing, to shape the radiation pattern. In order to avoid the grating lobes in the radiation pattern, linear arrays are usually spaced at half wavelength apart. Arrays with fewer elements than required by half wavelength spacing condition are called sparse arrays. Grating lobes in the radiation pattern of a sparse array can be reduced by eliminating the periodicity of the array. Many researchers have investigated the design of sparse one-dimensional arrays that use non-random spacing between elements [1–4]. However, Steinberg has shown that these algorithms produce sparse arrays that are no better, and often worse, in terms of average secondary side lobe level, than sparse arrays with randomly selected elements [5]. Lockwood has given the concept of effective aperture for designing sparse periodic linear antenna array used in ultrasound scanner [6]. Simulated annealing [7, 8], evolutionary algorithms such as genetic algorithm (GA) [9–14], and particle swarm optimization [15, 16] are also being used for the optimization of antenna arrays due to their global nature. PSO has been found to work better in certain kind of optimization problems. Compared to GA and SA, it is easily implemented and has least complexity.

PSO has been used for the synthesis of circular and hexagonal arrays for smart antenna applications [17]. PSO and modified PSO has been used for the cylindrical conformal array synthesis [18]. PSO has also been used for the synthesis of phased arrays [19]. The PSO has been used in electromagnetics for breast cancer detection [20]. Recently, PSO has been used for the synthesis of linear arrays of isotropic radiators, with minimum side lobe level (SLL) and null control [16]. In this paper, PSO is used to optimize the spacings between the elements of the linear array of half wave parallel dipoles to produce a radiation pattern with minimum SLL and null placement control.

The dipole is a practical radiator and used in many applications. The dipole antenna can be used as EMI sensor [21]. A fractal dipole antenna has been proposed for ultra wideband applications [22]. The optimization of V dipole and its three element Yagi Uda antenna has been carried out using Genetic Algorithm [23].The double dipole patch antenna having enhanced bandwidth for phased array synthesis has been reported in [24]. The theoretical analysis of vertical dipole antenna has been done in [25] and the radiation pattern analysis of parallel dipoles has been illustrated in [26]. The radiation pattern synthesis of a conformal dipole array has been report in [27]. The optimization of V dipole has been done recently by another evolutionary approach i.e., Bacterial foraging [28].

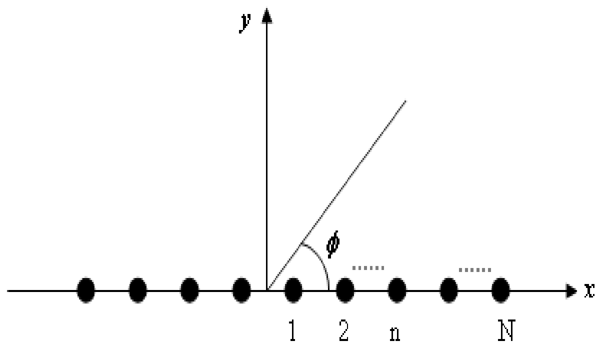

Figure 1. Geometry of $2N$ element symmetric linear array placed along the x-axis.

For a uniformly excited linear array having $2N$ isotropic elements placed symmetrically along the x-axis as shown in Figure 1, the array factor in azimuth plane is given by [16];

$$AF(\phi) = 2\sum_{n=1}^{N} \cos[kx_n \cos(\phi)] \tag{1}$$

where k is the wave number and x_n is the location of nth element. A half wave dipole is a practical radiator, which is most commonly used as array element in antenna arrays. For a linear array of half wave parallel dipoles placed on the x axis, the element pattern is given by [29],

$$elfactor = \left(1 - \sin^2(\theta)\cos^2(\phi)\right) \tag{2}$$

Thus, according to principal of pattern multiplication, the radiation field of a linear array of half wave dipoles becomes,

$$RF(\phi) = elfactor * AF(\phi) \tag{3}$$

The PSO has been used to find optimum location x_n, so as to have the radiation pattern having minimum SLL and nulls in specific directions. PSO has been discussed in the next section, followed by design examples in the next section. Finally, the work has been concluded.

2. PARTICLE SWARM OPTIMIZATION

PSO is an evolutionary algorithm based on the intelligence and cooperation of group of birds or fish schooling. It maintains a swarm of particles where each particle represents a potential solution. In PSO algorithm particles are flown through a multidimensional search space, where the position of each particle is adjusted according to its own experience and that of its neighbors. Table 1 shows some key terms used to describe PSO [15].

The algorithm can be stated as [30]:

(1) Define the solution space: Initialize an array of the population of particles with random positions and velocities in D dimensions in problem space.

(2) Evaluate the fitness function in D variables for each particle. The fitness function and the solution space must be specifically developed for each optimization; the rest of the optimization, however, is independent of the physical system being optimized.

(3) Compare each particle's fitness evaluation with pbest. If the current value is better than pbest, then save the current value as pbest and let the location correspond to the current location in D dimensional space.

(4) Compare the fitness evaluation with the population's overall previous best, i.e., gbest. If the current value is better than gbest, then save the current value as gbest to the current particle's array index and value.

(5) Update the position and velocities of particles as per the following equations:

$$v_n^{t+1} = w * v_n^t + c_1 * rand1(\,) * \left(pbest_n^t - x_n^t\right) + c_2 * rand2(\,) * \left(gbest_n^t - x_n^t\right) \quad (4)$$

$$x_n^{t+1} = x_n^t + v_n^{t+1} * \Delta t \quad (5)$$

where w is the inertia weight, c_1 and c_2 are two positive constants called cognitive parameter and social parameter and *rand1( )* and *rand2( )* are random number generators. c_1 and c_2 have taken as 2 and w is linearly damped with iterations starting at 0.9 and decreasing linearly to 0.4 at the last iteration [16].

(6) If the desired criterion is not met, go to step 2, otherwise stop the process.

It is important that the cost function can be calculated as efficiently as possible, as it will be calculated at every iteration of the

Table 1. Key PSO vocabulary.

Some Key terms used to describe PSO	
Particle/Agent	One single individual in the swarm
Location/Position	An agent's N dimensional coordinates which represents a solution to the problem.
Swarm	The entire collection of agents
Fitness or Cost	A single number representing the goodness of a given solution.
Personal best (pbest)	The location in parameter space of the best fitness returned for a specific agent.
Global best (gbest)	The location in parameter space of the best fitness returned for the entire swarm
Vmax	The maximum allowed velocity in a given direction

algorithm. The cost function should be designed so that it can lead the search. One way of achieving this is to avoid cost functions where many states return the same value. In antenna array problems there are many factors that can be used to evaluate fitness such as directive gain, SLL, beam width etc. For the current problem, we are interested in designing the geometry of a linear array with minimum side lobe level and null control in specific directions. Thus, the following fitness function has been used to evaluate the fitness [16].

$$Fitness = \sum_i \frac{1}{\Delta\phi_i} \int_{\phi_{li}}^{\phi_{ui}} |RF(\phi)|^2 d\phi + \sum_k |RF(\phi_k)|^2 \qquad (6)$$

where $[\phi_{li}, \phi_{ui}]$s are spatial regions in which the SLL is suppressed, $\Delta\phi_i = \phi_{ui} - \phi_{li}$, and ϕ_ks are the directions of the nulls.

3. DESIGN EXAMPLES

The PSO has been implemented in MATLAB$^{\text{TM}}$ 7.2 and simulation has been carried out taking different examples. The design problems for the simulation examples presented in this paper have been taken from [31]. The mutual coupling effect between the diploes has been ignored. The PSO has been run for 10,000 iterations and value of global best position has been noted.

The first example shows the design of 32 element array with SLL suppression in the regions [0°, 87°] and [93°, 180°] and nulls at 81° and

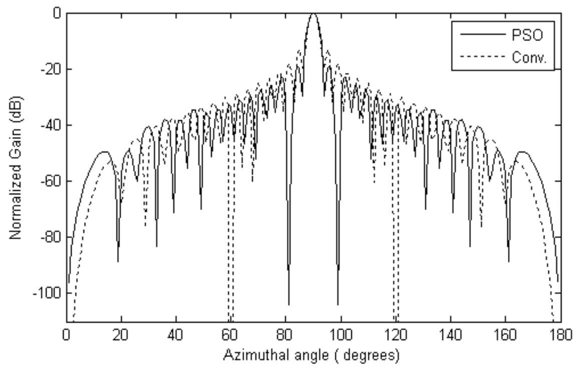

Figure 2. Normalized pattern of 32 element linear array of half wave dipoles. The region of suppressed SLL are [0°, 87°] and [93°, 180°], and prescribed nulls at 81° and 99°.

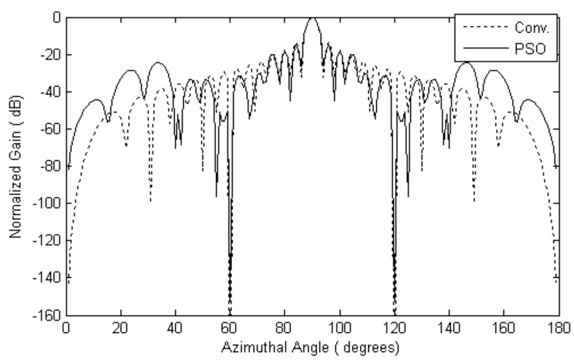

Figure 3. Normalized pattern of 28 element linear array of half wave dipoles. The region of suppressed SLL are [0°, 180°], and prescribed nulls at 55°, 57.5°, 60°, 120°, 122.5° and 125°.

99°. The array pattern has been shown in Figure 2. The nulls as deep as 100 dB have been obtained at desired null locations of 81° and 99°. All the sidelobes except the farthest have lower or comparable value of SLL compared to that obtained using conventional spacing. The array geometry obtained using PSO is given by,

X = [0.3793 1.4752 2.1510 3.2231 3.8388 4.8391 5.4492 6.4240 7.0921 8.0503 8.9132 9.9873 11.1627 12.6504 14.2845 15.9000]

The second example discusses the geometry of 28-element array of half wave dipoles placed on the x axis, designed for SLL suppression in the region [0°, 180°] and prescribed nulls at 55°, 57.5°, 60°, 120°, 122.5° and 125°. The azimuthal pattern is as shown in Figure 3. It can be seen that the nulls has successfully been achieved in desired locations. It can be observed that all the sidelobes except the farthest have lower value of SLL compared to that obtained using conventional spacing. The array geometry obtained using PSO is given by,

X = [0.3960 1.4592 2.4511 3.2669 4.3496 5.0710 6.0395 7.3285 8.2980 9.6484 10.2257 11.6535 12.1350 13.8530]

4. CONCLUSION

The use of PSO in the synthesis of non-uniform linear array of half wave parallel dipoles for the purpose of suppressed side lobes and null placement in certain directions has been illustrated in this paper. The mutual coupling effects have been ignored. PSO can be successfully used for the design of such multimodal problems. Further, use of PSO can also explored for application to synthesis of planar and conformal arrays of dipoles.

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