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OPTIMIZATION OF A SCANNABLE PATTERN FOR UNIFORM PLANAR ANTENNA ARRAYS TO MINIMIZE THE SIDE LOBE LEVEL

A. Reyna and M. A. Panduro

Unidad Académica Multidisciplinaria Reynosa-Rodhe
Universidad Autónoma de Tamaulipas (UAT)
Carretera Reynosa-San Fernando, Reynosa, Tamaulipas 88779, México

Abstract—The optimization of a scannable pattern for planar antenna arrays is dealt with. This design of Scannable Planar Arrays considers the optimization of the amplitude and phase excitation across the antenna elements by using the well-known method of Genetic Algorithms. Simulation results for Scannable Planar Arrays with the amplitude and phase excitation optimized by Genetic Algorithms are provided. Furthermore, in order to set which design case could provide a better performance in side lobe level, a comparative analysis of the performance of the optimized design case with a conventional phased planar array is achieved.

1. INTRODUCTION

Many antenna applications such as cellular systems, radar systems, smart antennas, etc., require the capability of steering the beam pattern in a wide scanning range. In this case, planar arrays are well suited for such applications where beam scanning is needed, particularly, in all azimuth plane [1, 2].

In the study of planar arrays, it has been considered the reduction of the side lobe level by optimally adjusting the positions of the antenna elements with uniform excitations [3–5]. Recently, it has been proposed in [6, 7] the design of a non-uniformly spaced planar array structure. This approach makes use of the thinned array theory [8–10] combined with the Gauss-Newton algorithm [6]. In [11] the differential evolution algorithm is used for the pattern synthesis of planar antenna arrays with prescribed pattern nulls by position-only and position-amplitude optimization.

In this paper, we present the design of a scannable uniform planar array considering the optimization of the amplitude and phase excitations across the antenna elements by using the well-known Genetic Algorithms (GA) [12–22]. Due to the great variety of parameters involved, optimization techniques such as GA are very appropriate tools to search for the best antenna array models.

The main objective of this paper is to investigate the behavior of the array factor for the design of planar antenna arrays in a uniform planar geometry considering the optimization of a scannable pattern in a wide scanning range. This design considers the synthesis of the array factor with desired characteristics of the side lobe level and the directivity in a wide steering range.

This paper is organized as follows. Section 2 describes the scannable planar array model. Section 3 presents a description of the objective function used by the evolutionary algorithm; then the simulation results are presented in Section 4. Finally, the conclusions of this work along with some future line of research are presented in Section 5.

2. PLANAR ARRAY MODEL

Consider a planar array of $M \times N$ antenna elements uniformly spaced in the x-y plane as shown in Figure 1. The array factor for the planar array shown in the Figure 1 is given by [23, 24]

$$\begin{aligned} AF(\theta,\varphi,I) = & \sum_{n=1}^{N}\sum_{m=1}^{M} I_{mn}\exp\{jk\,[x_{mn}(\sin\theta\cos\varphi-\sin\theta_0\cos\varphi_0) \\ & + y_{mn}(\sin\theta\sin\varphi-\sin\theta_0\sin\varphi_0)]\} \end{aligned} \tag{1}$$

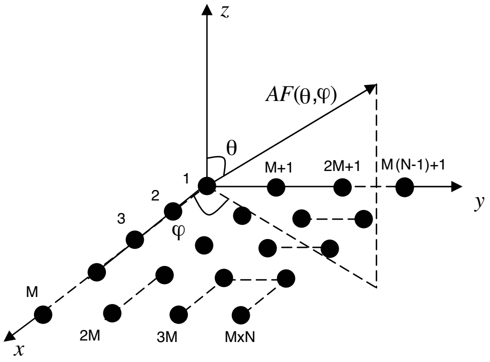

Figure 1. Steerable planar array with antenna elements uniformly spaced.

where x_{mn} and y_{mn} indicate the position of the mnth element of the array. In this case, the array factor for a planar array with phase excitation is created by adding in the appropriate element phase perturbations

$$\mathbf{P} = \begin{bmatrix} \delta\beta_1 & \delta\beta_2 & \cdots & \delta\beta_M \\ \delta\beta_{M+1} & \delta\beta_{M+2} & \cdots & \delta\beta_{2M} \\ & & \vdots & \\ \delta\beta_{M(N-1)+1} & \delta\beta_{M(N-1)+2} & \cdots & \delta\beta_{M\times N} \end{bmatrix} \tag{2}$$

where $\delta\beta i$ represents the phase perturbation of the ith element of the array, such that

$$AF\left(\theta, \varphi, I, \mathbf{P}\right) = \sum_{n=1}^{N} \sum_{m=1}^{M} I_{mn} \exp\left\{j\left[\psi_{mn} + \delta\beta_{mn}\right]\right\}. \tag{3}$$

In these equations, I_{mn} represents the amplitude excitation of the mnth element of the array, $\psi_{mn} = k[x_{mn}(\sin\theta\cos\varphi - \sin\theta_0\cos\varphi_0) + y_{mn}(\sin\theta\sin\varphi - \sin\theta_0\sin\varphi_0)]$, $(\theta_0,\ \varphi_0)$ is the direction of maximum radiation, $k = 2\pi/\lambda$ is the phase constant, θ is the angle of incidence of a plane wave in the elevation plane, φ is the angle of incidence in the azimuth plane, λ is the signal wavelength.

The idea of adding perturbations into the conventional array factor is so that the optimization algorithm searches possible optimal phase excitations in angles near the direction of desired maximum gain. The optimization process developed in this paper for generating arrays that have radiation patterns with low side lobe level will be based on (3).

3. OBJECTIVE FUNCTION AND THE TECHNIQUE USED

To deal with this design problem we use the method of Genetic Algorithms. We chose this algorithm for its ease of implementation. Besides its simplicity for implementation this algorithm has shown to be one of the most effective algorithms over an important set of difficult optimization problems [25]. Notice that with this selection we do not claim that GA is the best option for this particular problem: determining the best optimization algorithm for a particular antenna design problem remains an open problem. The procedure for GA is described as follows.

A set of 500 points is used to specify a desired array factor with direction of maximum gain in each angle of the scanning range. Each point represents the ith desired normalized radiation pattern value.

An individual is generated by the GA (amplitude excitations and phase perturbations of antenna elements). Each individual is in general represented by a vector of real numbers, that represents the amplitudes, and a vector of real numbers restrained on the range $(0, 2PI)$, that represents the phase perturbation of antenna elements.

The value of the objective function is calculated as

$$Of = (|AF(\theta_{SLL}, \varphi_{SLL}, I, \mathbf{P})|/\max|AF(\theta, \varphi, I, \mathbf{P})|) + (1/DIR(\theta, \varphi, I, \mathbf{P})) \tag{4}$$

where $(\theta_{SLL}, \varphi_{SLL})$ is the angle where the maximum side lobe is attained and *DIR* the directivity of the array factor. In this case both objectives (*SLL* and *DIR*) are uniformly weighted in the cost function. In this case, the design problem is formulated as minimize the objective function *of*.

A random population of individuals is generated and the genetic mechanisms of cossover, survival and mutation are used to obtain better and better individuals, until the GA converge to the best solution or the desired goals are achieved.

The results of using the evolutionary algorithm for the design of scannable uniform planar arrays are described in the next section.

4. SIMULATION RESULTS

The technique of GA was implemented to study the behavior of the array factor for scannable planar arrays. In this case, the array factor generated in the azimuth plane in the cut of $\theta = 45°$ is considered, i.e., the array factor for the steering range of $0° \leq \varphi_0 \leq 360°$ with an angular step of 30°. After a trial and error procedure the parameters of the simulations algorithm were set as follows: maximum number of generations $rmax = 500$, population size $gsize = 200$, crossover probability $pc = 0.95$ and mutation probability $pm = 0.1$. Parameter tuning in evolutionary computation is a very complex problem to solve [26], and it is still an active area of research [27]. We have set proposed parameters based mainly on our previous experience in solving similar problems [12, 13, 28]. The obtained results are explained below.

Figure 2 illustrates the behavior of the array factor for a steerable planar array with the amplitude and phase excitation optimized by the GA. In this case, the separation between antenna elements is set as $d = 0.5\lambda$ and it is illustrated for the example $N = 10$ and $M = 10$, in the scanning range previously mentioned.

As shown in the example of the Figure 2, the evolutionary algorithm generates a set of amplitude and phase excitations in each

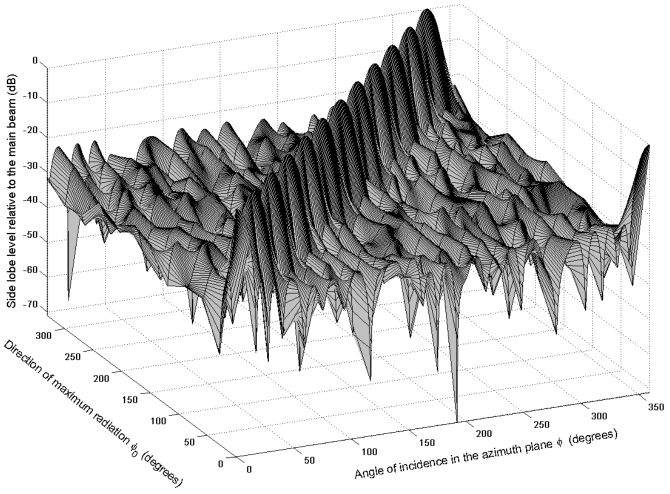

Figure 2. Behavior of the array factor for a steerable planar array in the proposed scanning range with the amplitude and phase excitation optimized by the GA for $N = 10$ and $M = 10$.

angle of the scanning range to provide a normalized array factor with a side lobe level <-20 dB in the steering range.

In Figure 3 it is shown a particular case for $\varphi_0 = 150^\circ$ in the cut of $\theta = 45^\circ$. In this Figure, it is shown a comparison of the array factor between this particular case, optimized with the evolutionary algorithm, and the conventional case, i.e., the conventional progressive phase excitation. From this Figure, it can be observed a considerable reduction of the side lobe level for the case optimized with the evolutionary algorithm with respect to the conventional case.

The numerical values of the side lobe level and the directivity for the array factor illustrated in Figure 2 are presented in Table 1. Table 1 illustrates that the design case with the amplitude and phase optimized by the GA could provide a better performance in side lobe level with respect to the conventional case. These low values of side lobe level for the optimized design case could be achieved with better values of directivity and the same aperture in both design cases.

The values of amplitude excitations and phase perturbations for the array factor illustrated in Figure 2 are shown graphically in Figure 4 and Figure 5. To be more illustrative, in these Figures it is considered the antenna element index of the planar array as shown in Figure 1, i.e., for the first linear array the element index is from 1 to $M = 10$, for the second linear array the element index is from $M + 1 = 11$ to $2M = 20$,

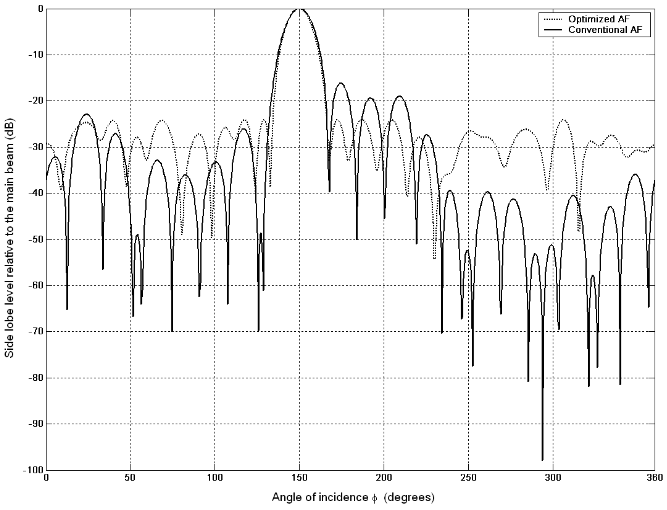

Figure 3. Comparison of the array factor between the particular case for $\varphi_0 = 150°$ in the cut of $\theta = 45°$ optimized with GA and the conventional case.

Table 1. Numerical values of the side lobe level and the directivity for the array factor illustrated in Figure 2.

Design case optimized with GA			**Conventional case**	
φ_0	***SLL*** (dB)	***DIR*** (dB)	***SLL*** (dB)	***DIR*** (dB)
0°	−22.2188	32.9620	−14.2418	33.0864
30°	−24.2846	33.8040	−16.1711	33.2632
60°	−24.4860	33.9745	−16.1639	33.2648
90°	−21.3458	33.4150	−14.2331	33.4168
120°	−24.0012	33.7401	−16.1598	33.2616
150°	−24.7379	33.7243	−16.1563	33.2591
180°	−22.5920	32.8748	−14.2292	33.4093
210°	−24.3958	33.4624	−16.1563	33.2591
240°	−24.1144	34.0938	−16.1598	33.2616
270°	−23.7050	33.5422	−14.2331	33.4168
300°	−25.1018	33.9017	−16.1639	33.2648
330°	−23.0084	33.5487	−16.1711	33.2632

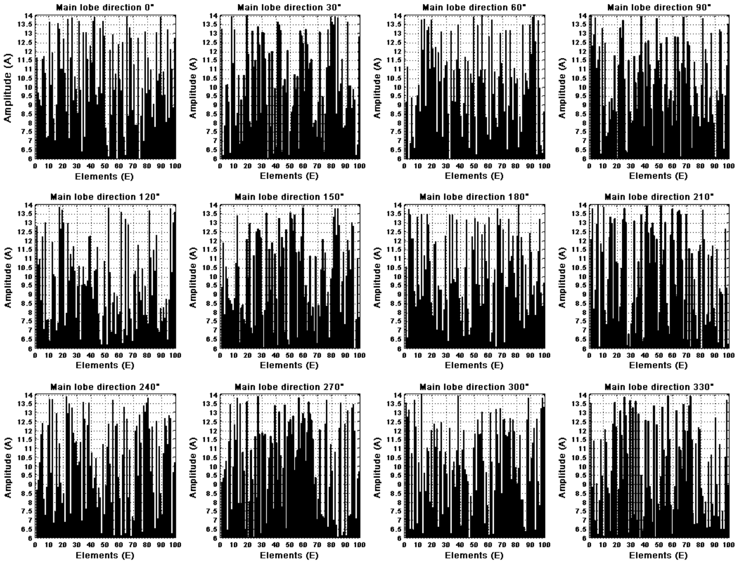

Figure 4. Amplitude distribution for the array factor illustrated in Figure 2.

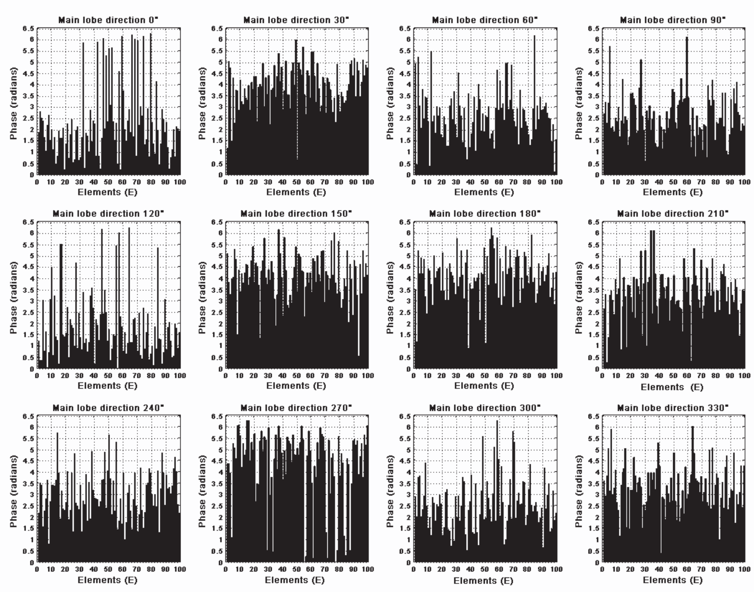

Figure 5. Phase perturbation distribution for the array factor illustrated in Figure 2.

and so on until we have $M \times N = 100$. In this case, the amplitudes weights could be realized in a real hardware setup rescaling all the complex coefficients before to apply them to a real system. In a real system, the amplitudes will be adjusted in such a way the conservation law of the energy will be preserved.

5. CONCLUSIONS

This paper illustrates how to model the design of scannable planar arrays with the amplitude and phase optimization for maximum side lobe level reduction using genetic algorithms. Experimental results reveal that the design of scannable planar arrays with the amplitude and phase optimized with the use of genetic algorithms could provide a lower side lobe level ($< -20\,\mathrm{dB}$), with respect to a conventional phased planar array. In this case, these values of side lobe level for the optimized design case are achieved with better values of directivity and the same aperture in both design cases.

Future research will be aimed at dealing with the application of evolutionary techniques in the optimization of scannable antenna arrays considering the feeding network in order to simplify the beamforming network.

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