We are IntechOpen,
the world's leading publisher of
Open Access books
Built by scientists, for scientists

4,800

Open access books available

122,000

International authors and editors

135M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities

CLARIVATE ANALYTICS
BOOK CITATION INDEX
INDEXED

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Design of Phased Antenna Arrays using Evolutionary Optimization Techniques

Marco A. Panduro[1], David H. Covarrubias[2] and Aldo L. Mendez[1]
[1]Reynosa-Rodhe Multidisciplinary Academic Center,
Universidad Autónoma de Tamaulipas
[2]CICESE Research Center, Tijuana
México

1. Introduction

Mobile and wireless communication systems have now arrived at the point where substancial advances in antenna technology have become a critical issue. The majority of these systems consist of an antenna array combined with an appropriate signal processing (Soni et al., 2002; Godara, 2002), i.e., the antenna elements are allowed to work in concert by means of array element phasing, which is accomplished with hardware or is performed digitally.

In these systems, the antenna array performance over a certain steering range is of primary concern. In this case, the antenna array design problem consists of finding weights that make the radiation pattern satisfy the desired characteristics (a maximum directivity, a minimum side lobe level, etc), so the direction of the main beam can be steered at will.

Generally, the design problem is formulated as an optimization problem. The design of antenna arrays has a nonlinear and non-convex dependence of elements parameters [Kurup et al. 2003], because of that, the interest has been focused on stochastic search techniques, such as simulated annealing (Murino et al., 1996), and mainly, genetic algorithms (GA's) (Ares-Pena et al., 1999; Haupt, 1994; Haupt, 1995; Panduro et al., 2005; Rahmat-Samii et al, 1999; Weile et al., 1997; Yan et al., 1997), widely used in electromagnetic problems, including the synthesis of phased antenna arrays (Mailloux, 2005; Hansen, 1998).

The antenna arrays optimization for improving performance represents an open line of research in the antenna design field. In the application of evolutionary optimization techniques for designing antenna arrays, it has been considered the design of different phased array structures, such as the linear arrays (Bray et al., 2002; Panduro, 2006) and the circular arrays (Panduro et al., 2006), among others. The design of planar arrays is dealt with in (Bae et al., 2005). In many design cases, it has been considered the optimization in the design of scannable arrays with non-uniform separation (Bray et al., 2002; Bae et al., 2004; Junker et al., 1998; Tian et al., 2005; Lommi et al., 2002).

In this chapter it is considered the case of designing scannable arrays with the optimization of the amplitude and phase excitations for maximum side lobe level reduction in a wide scanning range.

The purpose of this chapter is to investigate the behavior of the radiation pattern for the design of different phased array structures (linear and circular arrays) considering the

optimization of the amplitude and phase excitation across the antenna elements, by using the well-known method of Genetic Algorithms. Due to the great variety of parameters involved, optimization techniques such as Genetic Algorithms are very appropriate tools to search for the best antenna array models.

The primary focus of this chapter is to present a study of the application of GA techniques to the design of scannable linear and circular arrays in a uniform geometry considering the optimization of the amplitude and phase excitation across the antenna elements. This study considers the design of scannable linear and circular arrays to be a problem optimizing a simple objective function. This objective function considers the synthesis of the radiation diagram with desired characteristics of the side lobe level and the directivity in a wide steering range. The contribution of this work is to present a model for the design of scannable linear and circular arrays that includes the synthesis of the radiation diagram using the method of genetic algorithms.

The remainder of this chapter is organized as follows. Section 2 states the design of phased linear arrays. A description of the objective function used by the genetic algorithm and the obtained results for this design problem are presented in this section. Following the same design philosophy, the design of phased circular arrays is presented in the section 3. Discussions and open problems are presented in the section 4. Finally, the summary and conclusions of this work are presented in the section 5.

2. Design of phased linear arrays

The design of scannable linear arrays has been dealt with in many papers. In these documents, the study has been focused mainly to design scannable linear arrays with non-uniform separation (Bray et al., 2002; Bae et al., 2004; Junker et al., 1998; Tian et al., 2005; Lommi et al., 2002; Panduro et al., 2005)., i.e, the performance of the array is improved, in the sense of the side lobe level, optimizing the spacing between antenna elements. In this case, it is presented the design of scannable linear arrays optimizing the amplitude and phase excitations across the antenna elements. It is believed by the authors that the performance of the array could be improved substantially, with respect to the linear array with the conventional progressive phase excitation, if the amplitude and phase excitations are set or optimized in an adequate way. Next, it is presented the theoretical model for the design of scannable linear arrays.

2.1 Theoretical model

Consider a scannable linear array with N antenna elements uniformly spaced, as shown in figure 1. If the elements in the linear array are taken to be isotropic sources, the radiation pattern of this array can be described by its array factor (Stutzman, 1998). The array factor for a conventional linear array in the x-y plane is given by (Balanis, 2005)

$$AF(\theta, \mathbf{I}) = \sum_{n=1}^{N} I_n \exp\left\{j\left[k d_n \left(\cos\theta - \cos\theta_0\right)\right]\right\} \tag{1}$$

In this case, the array factor for a linear array with phase excitation is created by adding in the appropriate element phase perturbations, $\mathbf{P} = [\delta\beta_1, \delta\beta_2, ..., \delta\beta_N]$, $\delta\beta_i$ represents the phase perturbation of the ith element of the array, such that

$$AF(\theta, \mathbf{I}, \mathbf{P}) = \sum_{n=1}^{N} I_n \exp\left\{j\left[\psi_n + \delta\beta_n\right]\right\}. \tag{2}$$

In these equations, $\mathbf{I} = [I_1, I_2, ..., I_N]$, I_i represents the amplitude excitation of the ith element of the array, $\psi_n = kd_n\cos\theta_0$, θ_0 is the direction of maximum radiation, $k = 2\pi/\lambda$ is the phase constant and θ is the angle of incidence of a plane wave, λ is the signal wavelength.
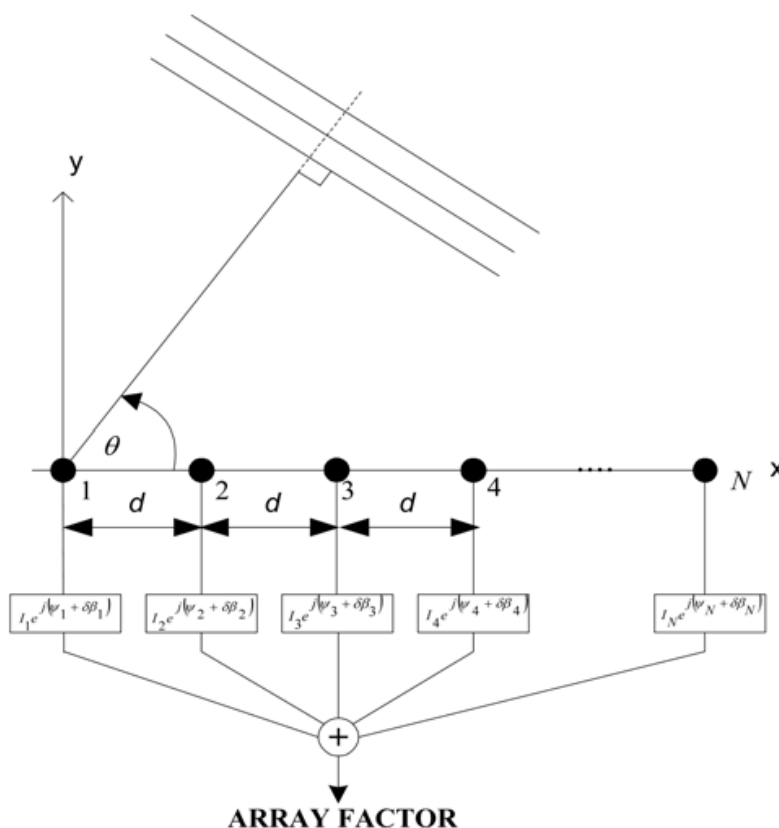

Figure 1. Steerable linear array with antenna elements uniformly spaced.

The idea of adding perturbations in the conventional array factor is 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 (2).
We now need to formulate the objective function we want to optimize.

2.2 Objective function used to optimize the design of linear arrays.
The objective function is the driving force behind the GA (Goldberg, 1989). It is called from the GA to determine the fitness of each solution string generated during the search. In this case, each solution string represents possible amplitude excitations and phase perturbations of antenna elements. As already being pointed out, the objective of the present study is to evaluate the radiation pattern of scannable linear arrays in a uniform geometry considering the optimization of the amplitude and phase excitation across the antenna elements. In this case, it is studied the behavior of the array factor for the scanning range of $50° \leq \theta_0 \leq 130°$ with an angular step of $10°$. In order to calculate the objective function of an individual, the procedure described below is followed.

1. A set of 1000 points is used to specify a desired radiation pattern with direction of maximum gain in each angle of the scanning range. Each point represents the ith desired normalized radiation pattern value.

2. 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, i.e., $\mathbf{I} = [I_1, I_2, ..., I_N]$, and a vector of real numbers restrained on the range $(0, 2\pi)$, i.e., $\mathbf{P} = [\delta\beta_1, \delta\beta_2, ..., \delta\beta_N]$.

3. The value of the objective function is calculated as

$$of = (|\mathrm{AF}(\theta_{MSL}, \mathbf{I}, \mathbf{P})| / max|\mathrm{AF}(\theta, \mathbf{I}, \mathbf{P})|) + (1/DIR(\theta, \mathbf{I}, \mathbf{P})) \qquad (3)$$

where θ_{MSL} is the angle where the maximum side lobe is attained, and DIR the directivity for the radiation pattern. In this case, the design problem is formulated as minimize the objective function of.

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

The results of using a GA for the design of scannable linear arrays are described in the next section.

2.3 Results obtained for the design of phased linear arrays

The method of Genetic Algorithms was implemented to study the behavior of the radiation pattern for scannable linear arrays. In this case, it is studied the behavior of the array factor for the scanning range of $50° \leq \theta_0 \leq 130°$. Several experiments were carried out with different number of antenna elements. In the experiments the algorithm parameters, after a trial and error procedure, were set as follows: maximum number of generations $rmax = 500$, population size $gsize = 200$, crossover probability $pc = 1.0$ and mutation probability $pm = 0.1$. A selection scheme combining Fitness Ranking and Elitist Selection (Goldberg, 1989) was implemented instead of a common weighted roulette wheel selection. The used genetic operators are standard: the well known two point crossover (Goldberg, 1989) along with a single mutation where a locus is randomly selected and the allele is replaced by a random number uniformly distributed in the feasible region. The obtained results are explained below.
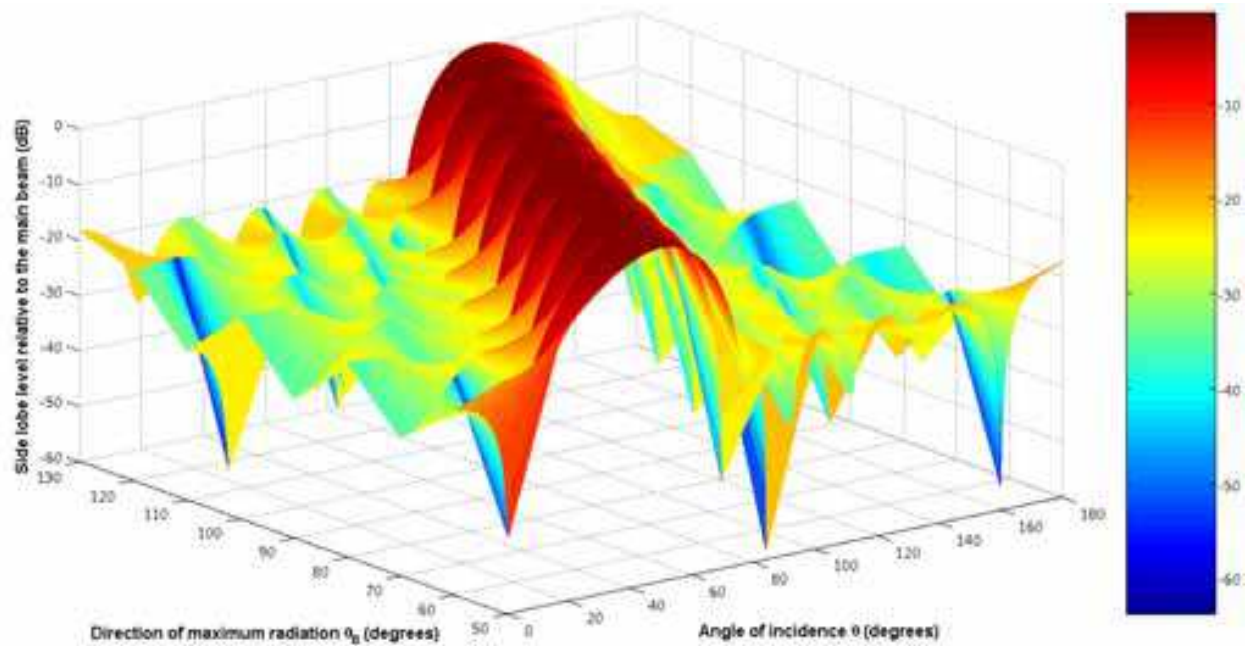
Figure 2 shows the behavior of the radiation pattern for a scannable linear array with the amplitude and phase excitation optimized by the GA. The separation between antenna elements is set as $d=0.5\lambda$. In this case, we illustrate the examples for a) $N=6$, b) $N=8$, c) $N=12$.

As shown in the examples of the Figure 2, the Genetic Algorithm generates a set of amplitude and phase excitations in each angle of the scanning range to provide a normalized array factor with a side lobe level < -20 dB in the steering range. The optimization of the array can maintain a low side lobe level without pattern distortion during beam steering.

Numerical values of the side lobe level, directivity, amplitude and phase perturbation distributions for the array factor illustrated in Figure 2 are presented in the Table 1.

Table 1 illustrates that the design case with the amplitude and phase optimized by the GA could provide a better performance in the side lobe level with respect to the conventional

case. These low values of the side lobe level for the optimized design case could be achieved with very similar values of directivity and the same aperture in both design cases.
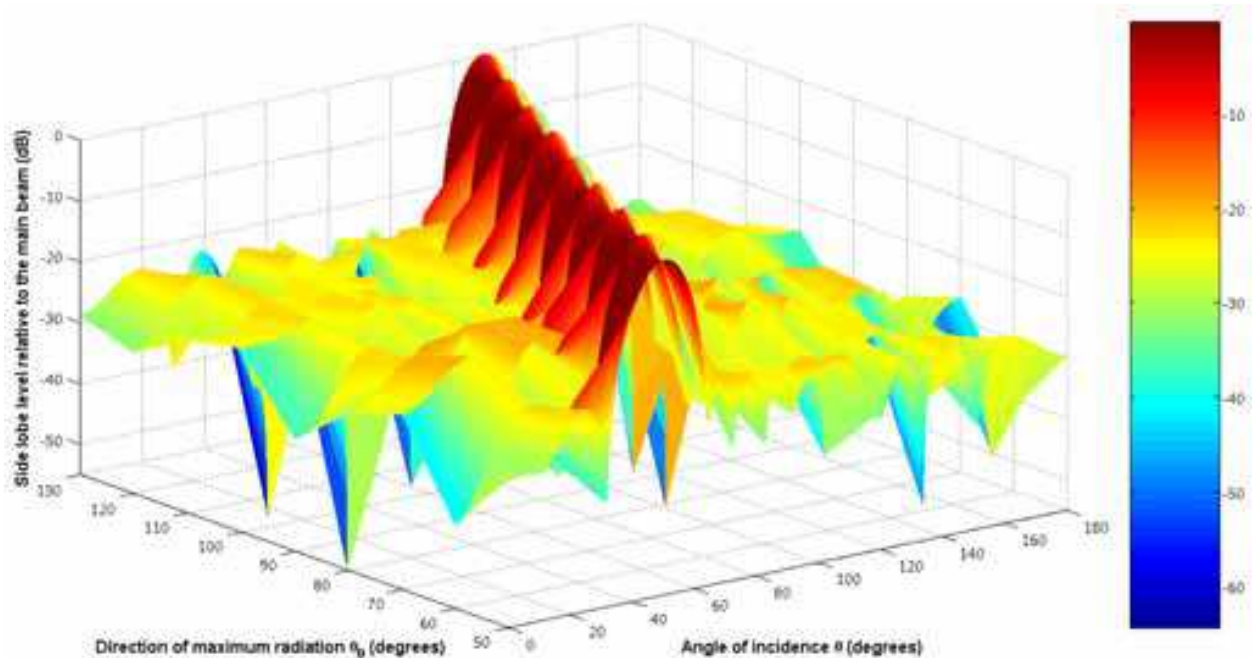

(a)
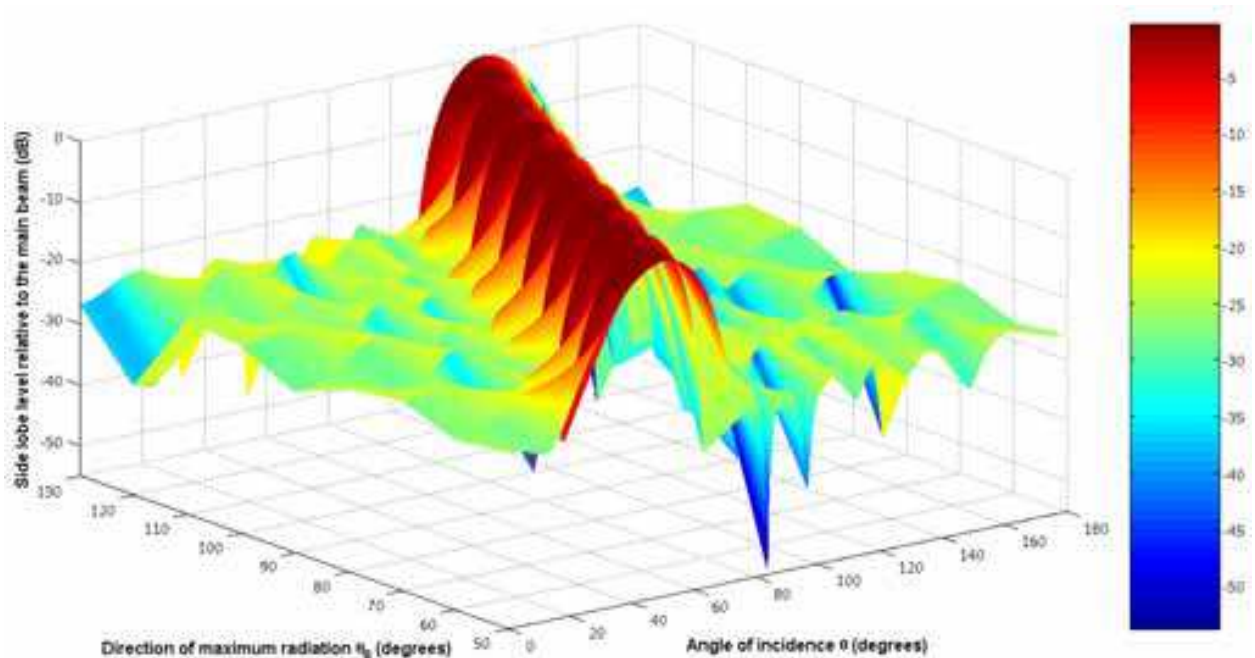
(b)

Figure 2. Behavior of the radiation pattern for a scannable linear array in a steering range of $50°\leq\theta_0\leq130°$ with the amplitude and phase excitation optimized by the GA, a) N=6, b) N=8, c) N=12.

(c)

Figure 2. (continued).

Design case with the amplitude and phase excitation optimized by the GA (N=6)					Conventional case	
θ_0	SLL (dB)	DIR (dB)	Normalised amplitude distribution	Phase perturbation distribution (deg)	SLL (dB)	DIR (dB)
50°	-20.57	5.95	5.2812 8.3264 11.1717 10.071 7.8738 5.0515	93.46, 103.56, 100.2, 102.06, 103.95, 94.22	-12.42	6.41
60°	-22.97	6.54	4.6352 8.5603 11.8683 11.6959 9.0046 5.0082	87.23, 92.48, 89.33, 90.30, 89.66, 89.65	-12.42	6.73
70°	-21.95	7.01	4.861 8.0166 11.481 11.6839 9.3365 5.5832	52.80, 58.69, 60.12, 60.05, 56.70, 53.96	-12.42	7.32
80°	-23.01	7.09	4.2881 8.753 11.427 11.4502 8.1468 4.6648	81.17, 73.84, 70.18, 71.08, 69.03, 83.96	-12.42	7.39
90°	-24.08	7.15	4.4101 8.6824 11.8247 11.9992 9.0169 4.3549	108.1, 114.48, 115.7, 114.46, 117.9, 107.2	-12.42	7.60
100°	-23.13	7.16	4.2918 7.6439 10.8717 11.7129 9.058 5.2613	90.28, 91.94, 95.46, 95.45, 93.59, 94.37	-12.42	7.39
110°	-23.49	6.86	4.1223 7.0177 10.4515 11.5757 9.0148 4.8233	75.35, 64.63, 60.83, 61.18, 64.72, 74.03	-12.42	7.32
120°	-21.13	6.60	4.5337 7.1531 9.9966 10.2654 7.6541 4.8863	83.29, 87.44, 94.70, 94.38, 87.42, 83.89	-12.42	6.73
130°	-20.14	6.03	5.3514 8.16 10.6545 10.117 7.8955 5.3136	89.32, 84.89, 89.40, 87.97, 84.96, 87.70	-12.42	6.41

(a)

Table 1. Numerical values of the side lobe level (SLL), directivity (DIR), amplitude and phase perturbation distribution for the array factor illustrated in Fig. 2, a) N=6, b) N=8, c) N=12.

θ_0	SLL (dB)	DIR (dB)	Normalised Amplitude distribution	Phase perturbation distribution (deg)	SLL (dB)	DIR (dB)
Design case with the amplitude and phase excitation optimized by the GA (N=8)					Conventional case	
50°	-23.37	7.22	4.087 4.9365 8.5532 10.2015 10.799 9.7949 7.5327 4.0191	100.41, 97.92, 103.90, 98.9, 101.2, 105.25, 101.56, 105.16	-12.79	7.48
60°	-21.34	7.90	4.2851 8.0845 9.094 11.5372 11.8051 10.633 7.121 5.8245	107.84, 95.16, 102.25, 105.2, 100.63, 105.05, 92.13, 105.7	-12.79	8.25
70°	-23.12	8.22	4.5748 6.4426 9.221 11.8394 11.792 10.3245 7.1393 4.827	66.60, 60.46, 59.03, 62.87, 63.14, 62.06, 62.34, 65.21	-12.79	8.51
80°	-22.20	8.43	4.5666 7.6476 9.81 11.5279 10.9044 9.513 6.7872 4.23	102.55, 104.3, 115.14, 103.7, 106.7, 109.5, 104, 94.6	-12.79	8.76
90°	-22.36	8.54	4.4301 7.6973 9.0958 10.86 10.8595 9.2315 5.927 4.6922	114.10, 102.9, 104.58, 99.58, 98.06, 104.4, 99, 111.62	-12.79	8.89
100°	-21.71	8.41	4.6048 6.5117 9.263 11.1713 11.982 9.9245 8.7118 4.8284	52.6, 76.44, 68.51, 77.12, 72.34, 73.01, 73.56, 57.24	-12.79	8.76
110°	-22.32	8.18	4.6991 7.3316 10.1467 11.8 11.00 9.1493 5.9517 4.2841	56.36, 53.19, 59.30, 47.77, 43.77, 54.19, 46.66, 53.58	-12.79	8.51
120°	-20.79	7.89	4.57 6.0843 9.1019 10.2557 9.7068 7.6138 6.6535 4.0621	105.23, 92.6, 104.36, 90.73, 95.37, 103.52, 92.73, 109.056	-12.79	8.25
130°	-23.37	7.25	4.141 6.4183 8.7271 11.4705 11.2 9.9689 7.0337 4.3883	101.21, 99.28, 102.08, 97.16, 97.26, 97.17, 98.01, 98.06	-12.79	7.48

(b)

θ_0	SLL (dB)	DIR (dB)	Normalised Amplitude distribution	Phase perturbation distribution (deg)	SLL (dB)	DIR (dB)
Design case with the amplitude and phase excitation optimized by the GA (N=12)					Conventional case	
50°	-21.43	9.20	5.834 5.819 7.759 8.9656 11.427 11.96 11.109 11.0136 10.232 7.295 6.952 4.6	97.6, 105.9, 101.5, 110, 90.5, 102.12, 95.96, 100.8, 102.54, 102, 103.1, 101.34	-13.05	9.48
60°	-23.56	9.58	4.001 6.1168 8.7636 10.192 11.69 11.563 11.6994 11.0176 8.62 6.31 4.908 4.13	88.59, 84.56, 86.26, 96.48, 87.56, 90.73, 86.58, 85.11, 102.20, 83.35, 94.8, 83.9	-13.05	10.05
70°	-19.08	10.01	5.971 7.8776 7.052 11.7027 10.658 10.886 11.539 10.817 10.136 8.486 6.636 6.371	67.94, 88.3, 85.7, 105.95, 98.62, 87.08, 92.3, 103.06, 99.9, 88.22, 96.42, 64.1	-13.05	10.41
80°	-19.11	10.23	7.3289 6.4067 9.1657 9.121 9.5598 11.419 11.164 9.1777 8.9068 6.812 6.353 4.022	17.87, 23.62, 11.35, 38.56, 19.02, 10.57, 17.68, 33.39, 19.07, 21.61, 32.24, 359.9	-13.05	10.62
90°	-23.77	10.18	4.3008 4.705 7.9 9.1098 11.2055 11.325 10.077 9.723 7.3412 5.32 4.784 4.0317	86.99, 94.23, 92.56, 93.22, 98.9, 101.5, 106.6, 103.37, 96.13, 92.3, 89.9, 86.84	-13.05	10.69
100°	-22.33	10.13	4.683 5.0336 8.207 10.2406 11.407 11.664 11.9685 10.84 8.61 6.992 5.307 5.076	95.2, 99.54, 104.57, 92.94, 104.3, 89.63, 87.54, 99.45, 89.9, 103.15, 97.5, 100.9	-13.05	10.62
110°	-22.38	10.01	4.748 6.2578 7.7439 8.9026 10.5646 11.617 11.78 10.328 10.562 6.653 6.363 4.356	84.30, 94.71, 79.67, 86.31, 73.17, 92.29, 82.51, 78.79, 84.01, 81.04, 87.27, 90.22	-13.05	10.41
120°	-21.25	9.67	4.5847 6.208 7.4537 9.5612 11.112 11.413 10.195 10.736 9.0616 7.4537 4.866 4.806	86.35, 70.13, 70.10, 71.82, 74.06, 81.96, 68.87, 82.64, 72.91, 66.77, 70.65, 88.11	-13.05	10.05
130°	-22.59	9.15	4.9722 5.9917 6.805 9.83 11.2548 11.3448 11.99 10.71 9.3777 7.7632 5.5745 4.92	91.46, 106.02, 94.3, 100.5, 101.1, 103.9, 100.8, 104.9, 99.45, 95.6, 99.57, 95.76	-13.05	9.48

(c)

Table 1. (continued)

From the results shown previously, it is illustrated a perspective of designing scannable linear arrays in a uniform structure with amplitude and phase optimization using genetic algorithms. The genetic algorithm efficiently computes a set of antenna element amplitude and phase excitations in each angle of the steering range in order to provide a radiation pattern with maximum side lobe level reduction in all scanning range. The optimized design case provides a considerable side lobe level reduction with respect to the conventional phased array, with very similar values of directivity and maintaining the same aperture.

The design case for phased circular arrays is presented in the next section.

3. Design of phased circular arrays

Among antenna array configurations, the phased linear array is the most common form employed in cellular and personal communication systems (PCS) (Song et al., 2001). However, 360° scanning of the radiation beam can be obtained by combining a few linear arrays whose sector scans add to give the desired 360° scan. This could result in objectionably high costs, i.e., the array cost, the control complexity, and the data processing load are increased. Furthermore, the radiation pattern varies with the scan angle, i.e., the gain of a linear array degrades in its end-fire directions giving way to interference coming from other directions (Durrani et al., 2002). Unlike the linear array, the performance of the circular arrays (Du, 2004; Goto et al., 1977; Tsai et al., 2001; Tsai et al., 2004; Vescovo, 1995; Watanabe, 1980) has not been extensively studied. Therefore, in this section it is presented the design of scannable circular arrays optimizing the amplitude and phase excitations across the antenna elements. It is believed by the authors that an evaluation of the array factor for scannable circular arrays optimized by GA's considering a scanning range in all azimuth plane (360°) has not been presented previously. Depending on the performance improvement that we could get (in terms of the side lobe level and the directivity) with respect to the circular array with the conventional progressive phase excitation, this information could be interesting for antenna designers. Next, it is presented the theoretical model for this design case.

3.1 Theoretical model

Consider a circular antenna array of N antenna elements uniformly spaced on a circle of radius a in the x-y plane. The array factor for the circular array shown in Figure 1, considering the center of the circle as the phase reference, is given by

$$AF(\phi, \mathbf{I}) = \sum_{n=1}^{N} I_n \exp\left[jka\left(\cos(\phi - \Delta\phi_n) - \cos(\phi_0 - \Delta\phi_n)\right)\right] \tag{4}$$

where $\Delta\phi_n = 2\pi(n-1)/N$ for $n=1,2, \ldots, N$ is the angular position of the nth element on the x-y plane, $ka=Nd$, i.e., $a=Nd\lambda/2\pi$, $\mathbf{I} = [I_1, I_2, \ldots, I_N]$, I_n represents the amplitude excitation of the nth element of the array, ϕ_0 is the direction of maximum radiation and ϕ is the angle of incidence of the plane wave.

As it was established for the linear array case, the array factor with phase excitation is created by adding in the appropriate element phase perturbations, $\mathbf{P} = [\delta\beta_1, \delta\beta_2, \ldots, \delta\beta_N]$, $\delta\beta_i$ represents the phase perturbation of the ith element of the array, such that

$$\varphi_n = ka[\cos(\phi-\Delta\phi_n)- \cos(\phi_0-\Delta\phi_n)] \tag{5}$$

where $\varphi_n=ka[\cos(\phi-\Delta\phi_n)- \cos(\phi_0-\Delta\phi_n)]$.

It is important to mention that as the center of the circle is taken as the phase reference in the array factor, it is considered a symmetrical excitation for the optimization process, i.e, the phase perturbation would be given in the next way $I_1\exp(j\delta\beta_1)$, …, $I_{N/2}\exp(j\delta\beta_{N/2})$, $I_{N/2+1}\exp(j\delta\beta_{N/2+1})=I_1\exp(-j\delta\beta_1)$, …, $I_N\delta\beta_N=I_{N/2}\exp(-j\delta\beta_{N/2})$. Note that we will have $N/2$ amplitude and phase excitations in the optimization process.
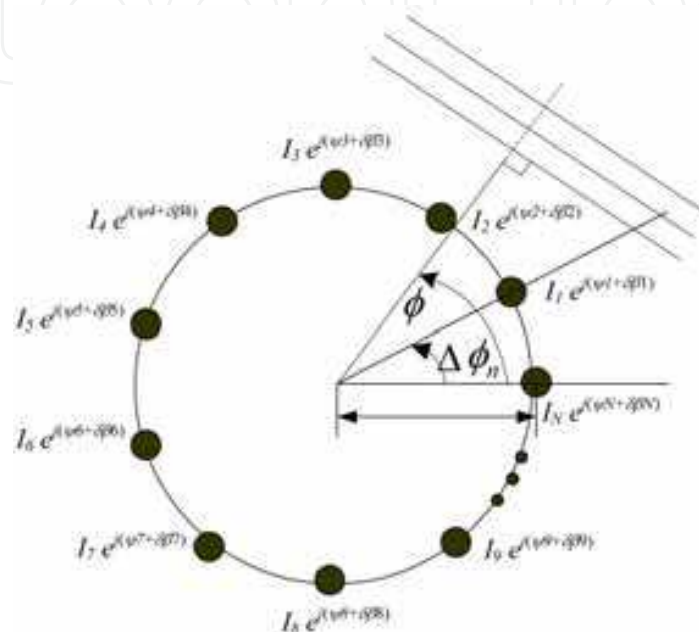
Figure 3. Array geometry for an N element uniform circular array with inter-element spacing d.

As already being pointed out, the objective of this section is to present an evaluation of the array factor for scannable circular arrays in a uniform geometry considering the optimization of the amplitude and phase excitation across the antenna elements. In this case, it is studied the behavior of the array factor for the scanning range of $0°\leq\phi_0\leq360°$ with an angular step of 30°. In this case, the objective function and the optimization process are set as they were presented for the linear array case, with the considerations of the scanning range and the symmetrical excitation aforementioned.

The results of using the GA for the design of scannable circular arrays are described in the next section.

### 3.3 Results obtained for the design of phased circular arrays

The application of a phased circular array has sense when it is used to have a scanning range in all azimuth plane (360°). Therefore, the method of GA's was implemented to evaluate the behavior of the array factor for the scanning range of $0°\leq\phi_0\leq360°$ with an angular step of 30°. Next, some examples of the obtained results for the design of scannable circular arrays are explained.

Figure 4 shows the behavior of the array factor for a scannable circular array with the amplitude and phase excitation optimized by the GA. In this case, the separation between

antenna elements is set as d=0.5λ, and it is illustrated the examples for a) N=12 and b) N=18. The numerical values of the side lobe level, directivity, amplitude and phase perturbation distributions for the array factor shown in Figure 4 are presented in the Table 2.
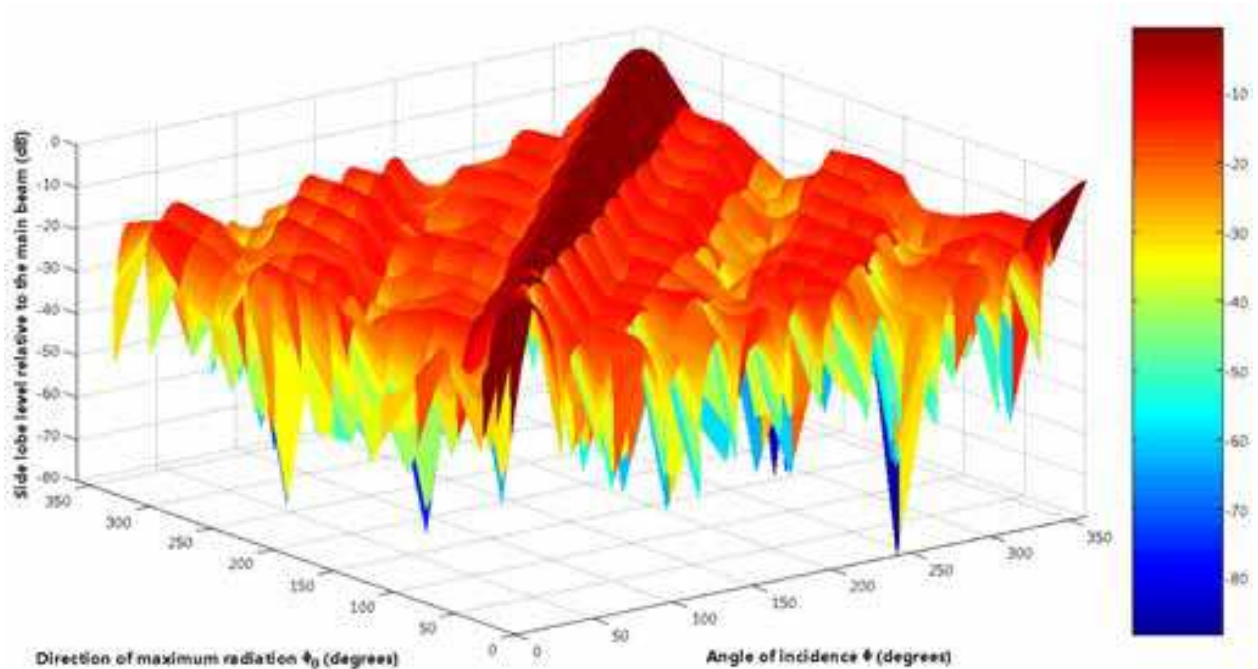
(a)
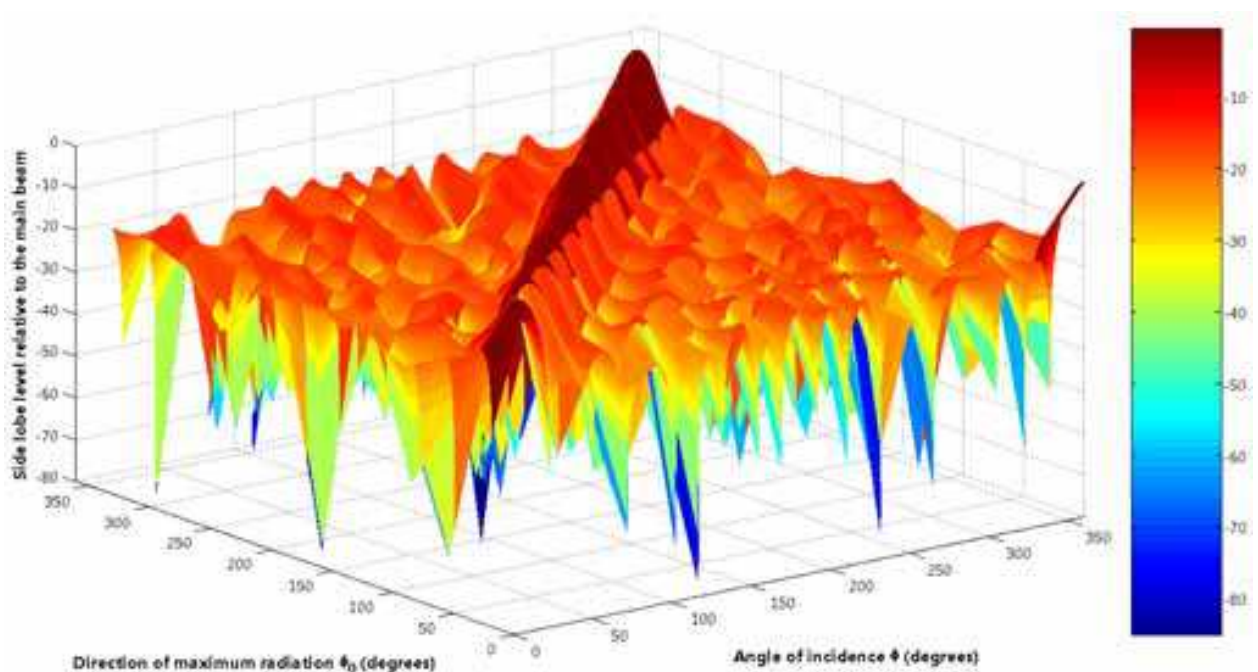
(b)

Figure 4. Behavior of the radiation pattern for a scannable circular array in a steering range of $0° \leq \phi_0 \leq 360°$ with the amplitude and phase excitation optimized by the GA, a) N=12, b) N=18.

As illustrated in the Figure 4 and the Table 2, the results of the side lobe level and the directivity for the optimized design are surprising. Observing the results, the conventional case of progressive phase excitation provides a SLL= -7.16 dB, and DIR=10.6 dB for a) N=12, and a SLL= -7.9 dB, DIR=12 dB for b) N=18. For the case of the optimized design, it is obtained a SLL_{min}= -12.17 dB, SLL_{max}= -13.68 dB and DIR_{min}=11.35 dB, DIR_{max}=11.56 dB for a) N=12, and a SLL_{min}= -13.50 dB, SLL_{max}= -16.74 dB and DIR_{min}=12.96 dB, DIR_{max}=13.23 dB for b) N=18.

These values mean a substantial improvement in the performance of the array for the design optimized by the GA with respect to the conventional case, i.,e, it is obtained a substantial improvement in the sense of the side lobe level and an improvement of about 1 dB in the directivity, maintaining the same scanning range and the same aperture.

Design case with the amplitude and phase excitation optimized by the GA (N=12)					Conventional case	
θ_0	SLL (dB)	DIR (dB)	Normalised Amplitude distribution	Phase perturbation distribution (deg)	SLL (dB)	DIR (dB)
0°	-13.26	11.50	8.9861, 7.0281, 6.0653, 7.1273, 8.6156, 13.6634	165.62, -109.48, 179.99, 108.64, -161.28, 149.09	-7.167	10.62
30°	-12.17	11.35	13.9516, 12.0757, 6.3265, 6.0282, 6.4862, 10.6097	18.52, -6.39, 39.77, -10.41, -26.71, 9.63	-7.165	10.65
60°	-12.78	11.53	10.444, 13.9698, 10.5989, 6.9121, 6.5014, 6.8659	-17.52, 25.97, -13.76, 57.97, -2.92, -59.70	-7.164	10.66
90°	-13.01	11.54	6.5076, 10.5052, 13.9753, 10.7816, 6.2717, 6.1824	65.56, -20.46, 26.50, -15.54, 57.09, 1.70	-7.165	10.66
120°	-13.42	11.50	6.0569, 6.8042, 10.9555, 13.8561, 8.9444, 6.1517	-17.08, 76.07, -11.95, 26.74, -30.83, 66.82	-7.167	10.66
150°	-13.18	11.56	6.2821, 6.0246, 7.0327, 9.669, 13.7562, 8.3516	114.21, 169.51, -114.93, 168.12, -151.91, 160.20	-7.165	10.65
180°	-12.48	11.50	9.1939, 6.015, 6.3482, 6.2204, 11.0839, 13.9433	14.83, -52.36, -5.56, 59.88, -11.88, 24.69	-7.164	10.65
210°	-13.24	11.47	13.7931, 9.391, 6.2871, 6.0677, 6.8493, 10.4153	-24.87, 19.04, -51.57, -19.56, 70.88, -12.32	-7.165	10.65
240°	-13.36	11.51	9.0782, 13.9387, 9.9896, 6.0713, 6.0022, 6.6342	-157.31, 155.52, -168.26 114.07, -176.6, -107.67	-7.167	10.66
270°	-12.74	11.50	7.3426, 11.2421, 13.9757, 11.0413, 7.2521, 6.0368	-52.84, 14.82, -26.20, 14.92, -51.18, -1.47	-7.165	10.66
300°	-12.51	11.48	6.0446, 7.609, 11.5202, 13.7836, 11.3168, 7.6133	-176.94, 125.17, -161.71 153.62, -165.07, 130.3	-7.164	10.66
330°	-13.68	11.54	6.0884, 6.0135, 6.2152, 9.2554, 13.9733, 10.1944	-113.97, -178.77, 110.13 -160.49, 152.53, -165.7	-7.165	10.66

(a)

Table 2. Numerical values of the side lobe level (SLL), directivity (DIR), amplitude and phase perturbation distribution for the array factor illustrated in Fig. 4, a) N=12, b) N=18.

Design case with the amplitude and phase excitation optimized by the GA (N=18)					Conventional case	
θ_0	SLL (dB)	DIR (dB)	Normalised Amplitude distribution	Phase perturbation distribution (deg)	SLL (dB)	DIR (dB)
0°	-16.74	12.98	9.606, 10.0796, 8.7306, 7.4423, 6.0729, 13.1574, 10.1184, 12.7586, 13.948	151, 137.36, -175.89, -3.65, 18.19, -175.31, -119.92, 176.34, -147.15	-7.9	11.91
30°	-14.59	13.15	13.8924, 13.4948, 12.384, 6.1859, 9.089, 7.2624, 8.7293, 6.1218, 10.978	-19.84, -9.665, -2.166, 27.55, -85.76, -19.785, 75.877, 25.36, 1.656	-7.9	12.0
60°	-14.85	13.05	7.7885, 10.2233, 13.7296, 10.4833, 8.1398, 10.8737, 6.5203, 6.1301, 9.315	140.02, 172.19, 156.37, 172.09, 139.6, -178.963, -40.93, 70.3, -170.776	-7.9	11.96
90°	-14.20	13.23	9.5658, 6.1554, 13.1213, 13.7249, 13.4988, 11.421, 6.0703, 8.8405, 7.243	101.49, -172.8, 175.48 166.3, 159.385, 177.2, 172.646, 105.8, -170.73	-7.9	12.0
120°	-14.08	12.96	6.8649, 6.1881, 10.5908, 7.0292, 11.4631, 13.7734, 9.398, 8.1573,10.8491	-137.484, 99.2, -9.642, -43.582, 1.26, -17.302, -10.043, -23.553, -9.312	-7.9	11.96
150°	-14.16	13.12	6.2198, 8.1045, 7.2332, 8.8087, 6.0134, 11.5031, 13.8558, 13.7171, 11.9379	-3.078, 76.838, 0.51, -77.027, 14.863, 2.441, -12.856, -10.865, 2.579	-7.9	12.0
180°	-16.21	13.17	11.2931, 6.9325, 9.8873, 6.0995, 7.026, 6.1086, 11.0604, 12.6843, 13.1782	-7.805, 28.515, 9.038, -102.785, -178.52, 8.36, -62.315, -27.75, -29.808	-7.9	11.95
210°	-14.85	13.18	13.4792, 13.806, 13.7676, 6.2475, 10.5248, 6.23, 8.2037, 6.1015, 9.0618	-144.58, -178.87, -165.5, 110.127, -112.7, -137.6, 111.07, 144.61, 176.76	-7.9	12.0
240°	-14.74	13.00	8.1184, 9.5482, 13.75, 11.8184, 7.7963, 12.1036, 6.0628, 6.5981, 8.9808	-149, -171.964, -159.465 176.53, -141.74, 178.43, 42.03, -50.722, 171.964	-7.9	11.96
270°	-14.07	13.15	8.649, 6.4937, 12.5178, 13.9531, 13.1291, 9.6387, 6.0478, 6.2315, 7.3053	76.656, -29.518, 4.1517, 6.344, 23.728, 7.36, 27.052, 71.543, -18.029	-7.9	12.0
300°	-13.50	13.00	6.6366, 6.4168, 10.2879, 7.7545, 9.5766, 13.9128, 11.4554, 7.9931, 11.7014	-68.05, 65.273, -169.852 -144.74, -179.74, -161.4, -176.4, -155.88, -165.66	-7.9	11.96
330°	-14.80	13.17	6.2548, 9.9819, 7.4138, 8.7991, 6.002, 10.5322, 13.7914, 13.7537, 13.7233	-116.06, 98.633, 136.89, -120.18, -126.33, -166.8 -152.76, -167, -165.53	-7.9	12.0

(b)

Table 2. (continued).

Now, if the results of the side lobe level and the directivity for the scannable circular array optimized by the GA (for N=12, shown in the Table 2a) are compared with the linear array case with conventional phase excitation (for N=12, shown in the Table 1c), we observe that the values of the *SLL* and *DIR* are a little better for the circular array case with the great advantage of having a scanning range several times bigger than the linear array case.

4. Discussions and open problems

The main objective of this chapter is to illustrate the application of an evolutionary optimization technique in the problem of designing scannable antenna arrays with geometry lineal and circular. A genetic algorithm is applied to evaluate the performance of scannable linear and circular arrays optimizing the amplitude and phase excitations across the antenna elements. The results obtained for the design of scannable linear and circular arrays reveal that the performance of the phased array could be improved substantially, with respect to the conventional case of progressive phase excitation, if the amplitude and phase excitations are optimized in an adequate way by an evolutionary algorithm.

There are many remaining open problems. In this case, we propose the following questions:

- Which is the best evolutionary algorithm for the problem in terms of solution quality and in terms of computation time?
- Given the algorithm, what is the best representation and the best genetic operators to use?
- Is there a better way to model or represent the problem in such a way to avoid the evaluation of the *SLL* and the *DIR* for each angle in the scanning range?
- What are the limits of performance for non-uniformly spaced phased arrays? How do these limits compare with the ones obtained by uniformly spaced phased arrays?

5. Conclusions

This chapter illustrates how to model the design of phased linear and circular arrays with the optimization of the amplitude and phase excitations for improving the performance of the array in the sense of the side lobe level and the directivity.

In the case of the scannable linear arrays, the experimental results illustrated that the design of scannable linear arrays with the amplitude and phase optimized with the use of genetic algorithms could provide a lower side lobe level (<-20 dB), with respect to a conventional phased linear array. In this case, these values of the side lobe level for the optimized design case are achieved with very similar values of directivity and the same aperture in both design cases.

For the case of the scannable circular arrays, the obtained results illustrated that the optimization of the array could provide a substantial improvement in the side lobe level and an improvement of about 1 dB in the directivity, with respect to the conventional case of progressive phase excitation. These improvements in the performance of the array are achieved maintaining the same scanning range, i.e., in all azimuth plane (360°), and the same aperture.

Future research will be aimed at considering the application and performance evaluation of new evolutionary algorithms in the design of different array geometries to understand which algorithm fits best a given problem. Also, the answer for the proposed set of questions will be investigated. Furthermore, it will be investigated the application of evolutionary techniques in the optimization of different phased arrays considering the feeding network in order to simplify the beam-forming network.

6. Acknowledgements

7. References

Ares-Pena, F. J., Rodriguez-Gonzalez, J. A., Villanueva-Lopez, E., & Rengarajan, S. R. (1999). Genetic algorithms in the design and optimization of antenna array patterns. *IEEE Transactions on Antennas and Propagation,* 47, 506-510.

Bae, J., Kim, K., & Pyo, C. (2005). Design of steerable linear and planar array geometry with non-uniform spacing for side-lobe reduction. *IEICE Transactions on Communications,* E88-B (1), 345-357.

Bae, J., Kim, K., Pyo, C., & Chae, J. S. (2004). Design of scannable non-uniform planar array structure for maximum side-lobe reduction. *ETRI Journal*, 26 (1), 53-56.

Balanis, C. (2005). *Antenna Theory-Analysis and Design*. Third Edition, New York: Wiley.

Bray, M. G., Werner, D. H., Boeringer, D. W., & Machuga, D. W. (2002). Optimization of thinned aperiodic linear phased arrays using genetic algorithms to reduce grating lobes during scanning. *IEEE Transactions on Antennas and Propagation,* 50, 1732–1742.

Du, K. L. (2004). Pattern Analysis of Uniform Circular Array. *IEEE Transactions on Antennas and Propagation*, 52 (4), 1125-1129.

Durrani, S., & Bialkowski, M. E. (2002). An investigation into the interference rejection capability of a linear array in a wireless communications system. *Microwave and Optical Technology Letters*, 35, 445-449.

Godara, L. C. (2002). *Handbook of Antennas in Wireless Communications*. CRC Press.

Golberg, D. E. (1989). *Genetic algorithms in search, optimization, and machine learning*. Addison-Wesley, Massachusetts.

Goto, N., & Tsunoda, Y. (1977). Sidelobe reduction of circular arrays with a constant excitation amplitude. *IEEE Transactions on Antennas and Propagation*, 25 (6), 896-898.

Hansen, R. C. (1998). *Phased Array Antennas*. New York: Wiley.

Haupt, R. (1994). Thinned arrays using genetic algorithms. *IEEE Transactions on Antennas and Propagation*, 42, 993-999.

Haupt, R. L. (1995). An introduction to genetic algorithms for electromagnetics. *IEEE Antennas and Propagation Magazine,* 37, 7-15.

Junker, G. P., Kuo, S. S., & Chen, C. H. (1998). Genetic algorithm optimization of antenna arrays with variable interlement spacings. *Proceedings of IEEE Antennas and Propagation Society International Symposium: Vol. 1* (pp. 50-53), Atlanta GA.

Kurup, D., Himdi, M., & Rydberg, A. (2003). Synthesis of uniform amplitude unequally spaced antenna arrays using the differential algorithm. *IEEE Transactions on Antennas and Propagation*, 51, 2210-2217.

Lommi, A., Massa, A., Storti, E., & Trucco, A. (2002). Sidelobe reduction in sparse linear arrays by genetic algorithms. *Microwave and Optical Technology Letters,* 32, 194-196.

Mailloux, R. J. (2005). *Phased array antenna handbook.* Artech House, Boston, Second edition.

Murino, V., Trucco, A., & Regazzoni, C. S. (1996). Synthesis of unequally spaced arrays by simulated annealing. *IEEE Transactions on Signal Processing*, 44, 119–123.

Panduro, M. A., Covarrubias, D. H., Brizuela, C. A., & Marante, F. R. (2005). A multi-objective approach in the linear antenna array design. *AEU International Journal of Electronics and Communications,* 59 (4), 205-212.

Panduro, M. A. (2006). Optimization of non-uniform linear phased array using genetic algorithms to provide maximum interference reduction in a wireless communication system. *Journal of the Chinese Institute of Engineers JCIE*, 29 (7), Special Issue: Communications, 1195-1201.

Panduro, M. A., Mendez, A. L., Dominguez, R., & Romero, G. (2006). Design of non-uniform circular antenna arrays for side lobe reduction using the method of genetic algorithms. *AEU International Journal of Electronics and Communications,* 60 (10), 713-717.

Rahmat-Samii, Y., & Michielssen, E. (1999). *Electromagnetic Optimisation by Genetic Algorithms*. New York: Wiley-Interscience.

Soni, RA, Buehrer, R. M., & Benning, R. D. (2002). Intelligent antenna system for cdma2000. *IEEE Signal Processing Magazine*, 19, 54-67.

Song, Y. S., Kwon, H. M., & Min, B. J. (2001). Computationally efficient smart antennas for CDMA wireless communications. *IEEE Transactions on Vehicular Technology,* 50, 1613-1628.

Stutzman, W. L., & Thiele, G. A. (1998). *Antenna Theory and Design*. Wiley, second edition.

Tian, Y. B., & Qian, J. (2005). Improve the performance of a linear array by changing the spaces among array elements in terms of genetic algorithm. *IEEE Transactions on Antennas and Propagation*, 53 (7), 2226–2230.

Tsai, J. A., & Woerner, B. D. (2001). Adaptive beamforming of uniform circular arrays (UCA) for wireless CDMA system. *35th Asimolar Conference*, Pacific Grove, CA.

Tsai, J. A., Buehrer, R. M., & Woerner, B. D. (2004). BER performance of a uniform circular array versus a uniform linear array in a mobile radio environment. *IEEE Transactions on Wireless Communications*, 3, 695-700.

Vescovo, R. (1995). Constrained and Unconstrained Synthesis of Array Factor for Circular Arrays. *IEEE Transactions on Antennas and Propagation*, 43 (12), 1405-1410.

Watanabe, F., Goto, N., Nagayama, A., & Yoshida, G. (1980). A Pattern Synthesis of Circular Arrays by Phase Adjustment. *IEEE Transactions on Antennas and Propagation*, 28 (6), 857-863.

Weile, D. S., & Michielsen, E. (1997). Genetic algorithm optimization applied to electromagnetics: A review. *IEEE Antennas and Propagation Magazine*, 45, 343-353.

Yan, K., & Lu, Y. (1997). Sidelobe reduction in array-pattern synthesis using genetic algorithm. *IEEE Transactions on Antennas and Propagation*, 45, 1117–1122.

Advances in Evolutionary Algorithms

Edited by Xiong Zhihui

ISBN 978-953-7619-11-4

Hard cover, 284 pages

Publisher InTech

Published online 01, November, 2008

Published in print edition November, 2008

With the recent trends towards massive data sets and significant computational power, combined with evolutionary algorithmic advances evolutionary computation is becoming much more relevant to practice. Aim of the book is to present recent improvements, innovative ideas and concepts in a part of a huge EA field.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

INTECH
open science | open minds