Int. J. Advanced Networking and Applications
Volume: 14 Issue: 03 Pages: 5423-5428(2022) ISSN: 0975-0290

Comparative Optimization Study of a Micro-Strip Antennas Array of Circular Forms by the Genetic Algorithms

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ABSTRACT

In this article, we present a theoretical approach allowing the optimization of a micro-strip antennas array with circular forms fed by coaxial probes. The proposed technique is based on genetic algorithms which allow us to optimize this network and to seek a global minimum of a function. These kinds of algorithms belong to the family of evolutionist algorithms. We introduce a synthesis problem by considering a rectilinear network with *P* radiating elements arranged regularly on the (*Ox*) axis. The implementation of the genetic algorithm being relatively greedy in resources (thus slow), we made the choice to apply the GA to a symmetric network. A comparative study between the different genetic algorithms corresponding to the different types of selections is highlighted through the synthesis results obtained.

Keywords - **Circular radiating elements, Genetic algorithm, Micro-strip antenna array, Optimization, Radiation pattern template.**

Date of Submission: Nov 06, 2022 Date of Acceptance: Dec 01, 2022

I. INTRODUCTION

Since their appearance in the 1950s, micro-strip antennas experienced growing success, thanks to their intrinsic physical characteristics (small size, lightness, conformability) and their ease of production.

These antennas are formed from a plate of dielectric substrate, one metalized face of which constitutes the ground plane and the metallic deposit on the other face constitutes the radiating element. The choice of the form of this radiating element depends on certain factors such as: the frequency of use, the radiated power, the type of polarization, the gain, as well as the bandwidth of the radiating element. The latter can be fed in different ways, by slot, by micro-strip line or by coaxial probe. We will use radiating elements of circular forms fed by coaxial probes (Fig 1).

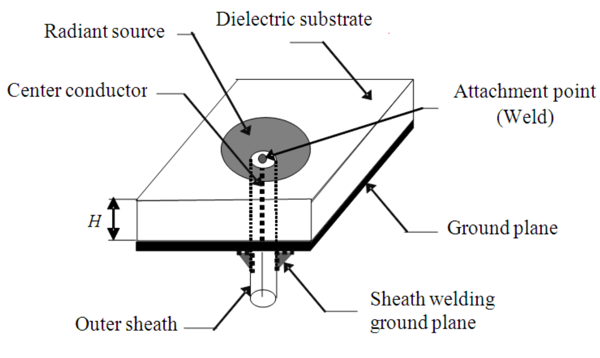

Fig 1. Structure of the Radiating Element

The network association of several micro-strip antennas makes it possible to compensate for the limitations of the characteristics of a single antenna and to improve their performance in terms of gain and radiation. One of the main advantages of gratings is their ability to scan the beam in certain directions in space. The process consists in feeding each source with an amplitude and a phase that are electronically controlled. This avoids, as in a reflector antenna, the use of heavy mechanical rotation systems which the high inertia prevents rapid exploration of space. The simplest method of studying this network association of micro-strip antennas is to admit that all the radiating elements are identical and that each element has the same radiation pattern in the presence of the others. The global radiation of the network will thus be the result of the combination of the radiations of the elementary sources, while neglecting the coupling between elements.

In the field of micro-strip antennas, many tools for theoretical analysis and synthesis have been developed [1]. Synthesis, whether deterministic or stochastic, is most often used in the development of antenna arrays, so that the radiation pattern meets a desired template. In our study we are interested in the synthesis of a symmetrical rectilinear network of micro-strip antennas with circular forms fed by coaxial probes operating in emission, using the genetic algorithms. The purpose of this optimization is to seek the optimal combination of the different parameters so that the network satisfies specifications (a template).

The genetic algorithm is an original statistical method used to optimize the array of micro-strip antennas and to find the global minimum of a function.

Volume: 14 Issue: 03 Pages: 5423-5428(2022) ISSN: 0975-0290

II. GENETIC ALGORITHM

Genetic algorithms [2][3][4] are an adaptive research technique, inspired by the mechanisms of natural evolution. They have been successfully applied to a wide domain of optimization problems. Genetic algorithms are an approach capable of finding optimal solutions to optimization problems with a large number of states to explore. While traditional search algorithms often impose severe constraints on the functions to be minimized such as continuity, differentiability, G.A's work differently by carrying out a global probabilistic search and thus circumventing most of these constraints [2][5].

The G.A works on a population of points, called chromosomes, distributed throughout the search space. A chromosome is made up of the parameters to be optimized, coded in binary and placed end to end. The goal is to search the optimal combination of these parameters giving rise to the maximum evaluation. At each generation a new population is created composed of chromosomes better adapted to the environment as it represented by the evaluation function (fitness) [2][3]. To the extent the generations, the chromosomes will tend towards the optimum of the evaluation function. The creation of a new population is established from the previous one as follows:

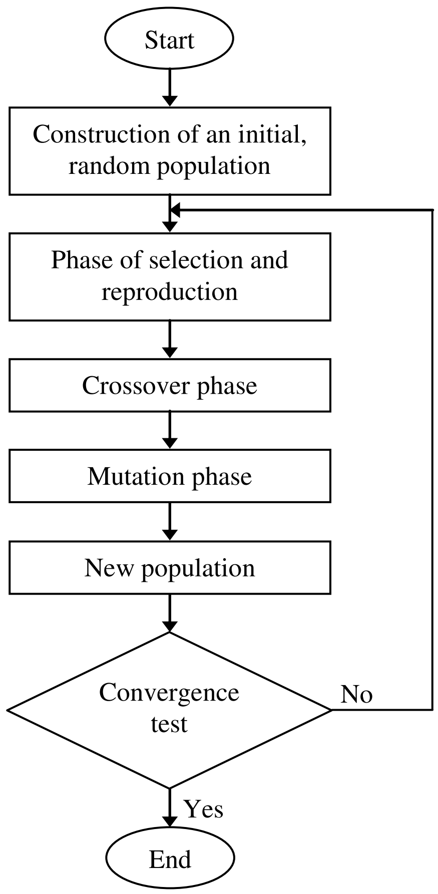

Fig 2. Genetic Algorithm

- **Selection and reproduction phase:** It allows individuals in a population to survive, reproduce or die. Each individual is determined by its selective value, relative to the average of the performance of all individuals in the population. The higher its value is above the average, the greater the chance of the individual to be reproduced. In this context, several selection methods are proposed to improve the performance of the GA:

1. *Selection by decimation*: It a selection method that proceeds by ranking the *i* individuals of the population according to their values of the evaluation function. Individuals are ranked from the best (first) to the worst (last). Consequently, a minimum threshold of the fitness function is fixed as a cut-off point which allows the deletion of all the individuals who appear to be undesirable from the population (the individuals who present themselves with a fitness function lower than the threshold). Thus, only the best (selected) form the new generation by random mating between them.

2. *Proportional selection*: This is the most widely used strategy, individuals *i* are selected according to a given probability of selection. It uses the metaphor of a casino roulette, which has as many boxes as there are individuals in the population and where the size of these boxes would be proportional to the adaptation of each individual. The game being launched, the selected individual is designated by the stopping of the ball on his square. If the boxes are unrolled on a line segment, the selection of an individual amounts to randomly choosing a point of the segment with a uniform probability distribution. The variance of this process is high. By bad luck, it possible at the limit that an individual of poor quality is selected for reproduction as many times as there are individuals replaced. It is also possible that an individual with a good adaptation value is never selected. This phenomenon is responsible for the genetic drift that allows some individuals to "survive" at the expense of better individuals. To limit this risk, the size of the population must be large enough.

3. *Tournament selection*: Tournament selection is an alternative to proportional selection techniques. The simplest tournament consists of randomly choosing a number of individuals from the population, and selecting for reproduction the one with the greatest adaptation. Over the course of a generation, there are as many tournaments as individuals to replace. Individuals that participate in a tournament remain in the population and are available again for subsequent tournaments. The variance of this process is high. Selection pressure is adjusted by the number of participants in a tournament, choosing many participants leads to high selection pressure because an average or weak individual will have less chance of being selected

than in the case of a binary tournament, reduced to two individuals.

- **Crossover phase:** Traditionally, crossover is seen as the essential search operator of a genetic algorithm. This operator combines the genotypes of two individual's parents to give rise to two new individual's children. This is an essential phenomenon that makes it possible to explore all the possible solutions of the problem. It is broken down into two phases: the first consists of choosing randomly the couples that will be crossed, the second performs the crossing.

- **Mutation phase**: This third operator is introduced to compensate for the disappearance of information (of bits) from the population. It role consist to modify randomly, with a certain probability, the value of a bit.

III. APPLICATION

In this part, we discuss the synthesis of a rectilinear network. The implementation of the genetic algorithm being relatively greedy in resources (thus slow); we made the choice to apply the GA to the symmetric network. We try to highlight the particularities of GA in its application to the synthesis and optimization of a micro-strip antennas network of circular forms.

III.1. SYNTHESIS PROBLEM

Let us consider a rectilinear array with P radiating elements arranged regularly on the (Ox) axis. Its directivity diagram is written [1]:

$$F(\theta,\phi)=\frac{f(\theta,\phi)}{F_{Max}}\sum_{i=1}^{P} a_i \, exp\left[j\left(k_0 \, x_i \, sin\theta cos\phi+\alpha_i\right)\right] \qquad (1)$$

with

$f(\theta,\phi)$: diagram of the elementary source [6]

k_0 : wave number ($k_0=\frac{2\pi}{\lambda}$)

θ, ϕ : angular directions

a_i, α_i : amplitude and phase of the feeding complex excitation

The directivity pattern $F(\theta,\phi)$ is a function of the two direction angles θ and ϕ. By fixing ϕ the diagram $F(\theta,\phi)$ will be conformed in a plane, for example the plane E or the plane H. By considering a symmetrical spatial distribution and in the case of an even number of elements (P=2N), the antenna array will have the normalized directivity pattern:

$$F_s(\theta)=\frac{f(\theta)}{F_{s_{Max}}}\sum_{i=1}^{N} a_i \, cos\left(k_0 \, x_i \, sin\theta+\alpha_i\right) \qquad (2)$$

The synthesis problem therefore consists in finding the distribution and/or the feeding law allowing to approach a certain desired diagram $F_D(\theta)$ (Fig 3) [7].

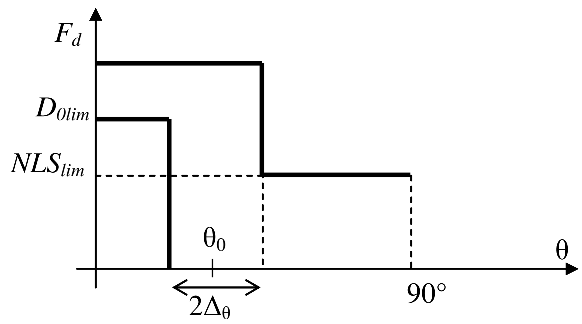

Fig 3. Half Template Characterizing the Desired Diagram

III. 2. APPLICATION OF THE GENETIC ALGORITHMS

In the context of GA, we liken the network of micro-strip antenna to a chromosome whose genes represent the network parameters (A_i, α_i, and x_i as it happens) [8].

The GA proceeds in its optimization phase as follows: we first create a population of individuals randomly, in our case it will be a matrix of dimensions $L\times C$ where:

- L: the number of rows equal to the number of individuals in the population.
- C: the number of columns equal to the number of the network parameters multiplied by the number of bits of the simple binary code used.

This matrix therefore contains an $L\times C$ number of "0" and "1". We then evaluate the strength (or the aptitude) of each individual of this generation by calculating their evaluation function. For this, we decode the chromosome corresponding to each individual, we will use for this purpose the formula of the following equation for a decoding of N bit genes:

$$P=\frac{P_{max}-P_{min}}{2^N}\sum_{i=0}^{N-1} 2^i \, b_i+P_{min} \qquad (3)$$

P_{max} and P_{min} are the upper and lower bounds of the interval of parameter values and b_i is the bit of order i along the gene corresponding to parameter P (P can be one or more parameters A_i, α_i, or x_i).

The only physical link between the genetic algorithm and the optimization problem is realized by the evaluation function fitness which is given by the following formula:

$$fitness = Max - F_s(\theta') \qquad (4)$$

with:

Max: a positive real number greater than the largest value that $F_s(\theta)$ can take.

θ' : the angle corresponding to the position of the largest secondary lobe of $F_s(\theta)$.

The vector P obtained will be introduced into the function $F_s(\theta)$ in order to evaluate the fitness function of this individual.

The GA being a "maximize" by default, it will tend to maximize this difference by decreasing the value of $F_s(\theta')$.

The GA will then select the individuals according to one of the three selection methods: by decimation, proportional and by tournaments. This is the parent selection phase. After coding, the operators of the GA will intervene for the reproduction; this is the role of the operations of crossing and mutation. The children's chromosomes are decoded again, which will give new parameters. These parameters give rise to a maximum level of secondary lobes at least lower than that of the older generations. We will select children who will be, by the very fact of their survival, parents in turn, by growing and mutating them.

These operations are repeated as long as a given number of generations are not reached or as long as the genetic algorithm does not converge towards an optimal individual.

III. 3. Synthesis Results

We will realize our synthesis on a rectilinear network [9] [10] with a single optimization parameter: the amplitude of the elements feed. We consider a regular and symmetrical rectilinear network with $2N$ elements localized in x_i and weighted by the feed coefficient a_i.

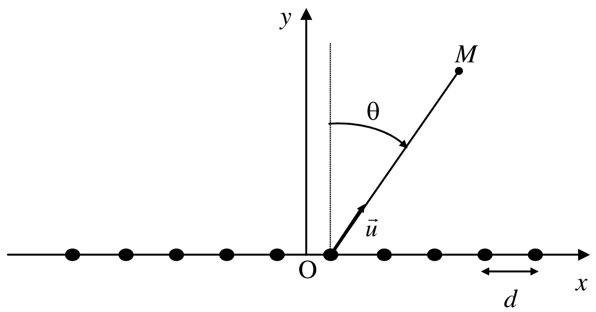

Fig 4. Rectilinear Array of Circular Radiating Elements

The normalized diagram is written:

$$F_s(\theta) = \frac{f(\theta)}{F_{s_{Max}}} \sum_{i=1}^{N} a_i \cos(k_0 x_i \sin\theta) \quad (5)$$

The synthesis is reduced to the feed law of the radiating elements defined by the vector $A=[a_1, a_2, \cdots, a_N]$, with: $0 \le a_i \le 1$, normalized amplitude distribution.

The results were all obtained for a symmetrical rectilinear array of micro-strip antennas in circular forms and operating at the frequency of 5 Ghz. Regarding optimization by GA, we chose to use the three types of selection (by decimation, proportional and by tournaments) in order to make a comparative study between this latter three.

For each selection method we considered a rectilinear network containing 20 radiating elements of circular forms. For genetic characteristics, we have:

- Parameter coding on 16 bits
- Number of individuals per population: 60
- Number of generations: 20
- Probability of crossing: 0.8
- Probability of mutation: 0.01

Fig 5, 6 and 7 represent the radiation patterns of the network where the selections used are respectively proportional, by tournaments and by decimation. In these figures, the radiation pattern $F(\theta)$ is given by the curve D_i while the synthesized radiation pattern $F_s(\theta)$ is given by the curve D_s.

Considering the symmetry of the studied network, we present in tables (1, 2 and 3) the values of the obtained feeds amplitudes for each radiating element of the half-network and this for the different types of selections.

- **Optimization using proportional selection:**

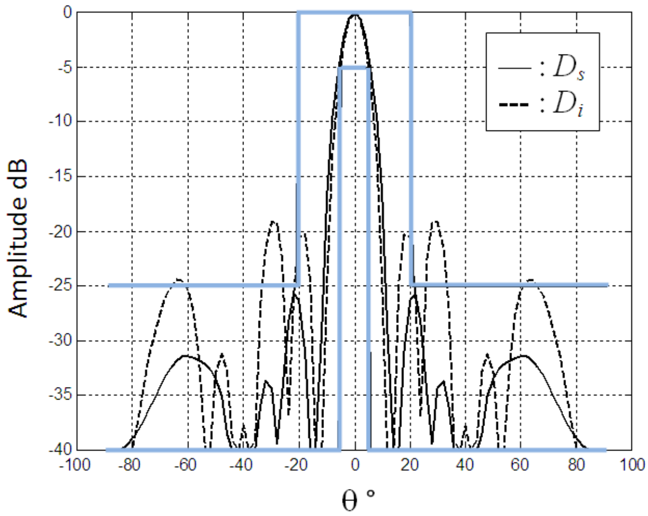

Fig 5. Radiation Pattern
(DO_{lim}= -5dB ; NLS_{lim}= -25dB)

Table 1. Feed Amplitude Value for Each Element Proportional Selection

Source	Amplitude
1	0.2980
2	0.3019
3	0.3843
4	0.8000
5	0.8313
6	0.8509
7	0.9647
8	0.6392
9	0.5411
10	0.2470

- **Optimization using tournament selection:**

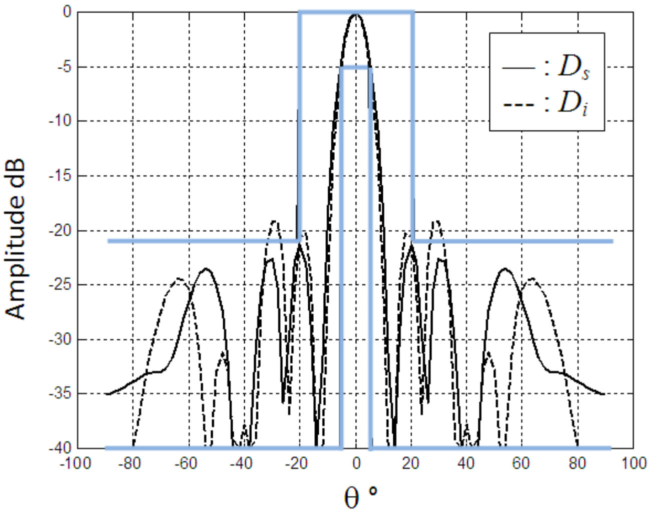

Fig 6. Radiation Pattern
(DO_{lim}= -5dB ; NLS_{lim}= -21dB)

Table 2. Feed Amplitude Value for Each Element Tournament Selection

Source	Amplitude
1	0.5411
2	0.4000
3	0.5843
4	0.6431
5	0.6588
6	0.9411
7	0.7333
8	0.7333
9	0.6627
10	0.1294

- **Optimization using decimation selection:**

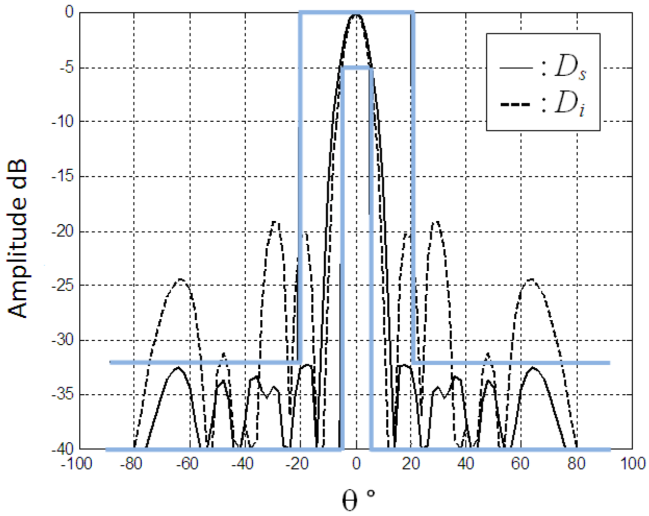

Fig 7. Radiation Pattern
(DO_{lim}= -5dB ; NLS_{lim}= -33dB)

Table 3. Feed Amplitude Value for Each Element Decimation Selection

Source	Amplitude
1	0.2784
2	0.4156
3	0.6901
4	0.9411
5	0.8509
6	0.8352
7	0.7450
8	0.4313
9	0.2470
10	0.2509

We notice, through Fig 7, that the secondary lobes level of the synthesized radiation pattern is clearly lower than that of the other two Fig 5 and 6. This implies that, in our study, the selection by decimation gives us better results than those of the other types of selections used (proportional and by tournaments). This is mainly due to the fact that the decimation selection method only selects the individuals best suited to the evaluation function, while in the case of the other two types of selection a better individual may not be selected.

IV. Conclusion

This article presents an approach allowing the optimization of a symmetrical rectilinear network of micro-strip antennas of circular forms fed by coaxial probes. This optimization consists in using the genetic algorithm so that the radiation pattern of this network comes as close as possible to the desired pattern which, in this case, is specified by a template. This approach has the advantage of escaping the local solutions of deterministic methods and makes it possible to approach the global minimum. It should be noted that the use of the different types of selections allowed us to conclude that the best selection to use in this kind of problem is selection by decimation. These latter proceeds by removing all undesirable individuals from the population, thus only the individuals best suited to the evaluation function (fitness) are selected.

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