An Improved Real-Coded Genetic Algorithm for Synthesizing a Massive Planar Array

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Abstract—The design of the Bi-State Antenna Massive Planar Array contributes to the mitigation of the energy consumption using the genetic algorithm under the constraints of minimizing the sidelobe level (SLL) and controlling the changing of the first null beamwidth (FNBW). Usually, Planar arrays are employed in communication applications based on battery usage such as portable radars. This paper optimizes a Uniform Rectangular Array (URA) with 1600 identical antenna elements using a Real-Coded Genetic Algorithm (RCGA). The optimization process is performed because the optimum set of the current excitation weight of radiating elements is found in the form of the ON-OFF state to conserve the consumed power. Hence, the highest performance of the Array Factor (AF) and the desired Beamwidth is selected. The main contribution presented in the paper is the ability to optimize a large number of array elements using the RCGA algorithm by dividing the array into a subset of arrays. The simulated results are performed to verify the effectiveness of the genetic thinned URA. The equivalent of 24.4% of the energy consumption is saved by selecting the antenna elements that could be scrambled with high effectiveness. In this paper, the results were obtained using MATLAB CAD Ver. 2018a as a platform.

Index Terms—RCGA, power saving, planner array, cost function, bi-state antenna.

I. Introduction

Saving power term is important in wireless communication especially for that system using a battery power supply [1]. Antenna Arrays are widely deployed in communication linking structure, especially in radar applications. Therefore, serious thinking needs to be considered to provide energy consumption. Some researchers have studied battery behavior and increased battery storage [2], besides to studying the communication channel and determine the nature of the signal mapping through channel behavior to introduce new modified mapping and modulation schemes to extract saving power like [3]. The array of antenna consists of an assembly of radiation components that arranged in specific geometrical shapes. These radiation components in most cases are identical and uniform spaced [4]. The main benefit of arrays is the high directivity in addition to high performance compared to the single antenna with the same kind of radiation elements [5]. The planar array is popular in beneficial applications in radar, sonar, & sensor networks, satellite communications, and medical imaging [6]. These arrays can be formed as a linear, planar or spherical also the distribution of space can be acquired by using different methods, such as empirical and iterative [7]. There have been many types of research in the non-uniform array [8]. However, Oraizi [9] designed a non-uniform space linear array that was based on Gaussian Quadrature using scales or weights of element spacing. Particle Swarm Optimization (PSO) and the Genetic Algorithm (GA) are two well-known optimization algorithms for optimizing beamforming, directivity, and side lobe suppression [10]. The challenge of optimizing processes in continuously search area is crucial since it is usually used to solve practical problems such as designing the antenna under specific conditions. Hence, evolutionary PSO [11] and Dynamic Multi-Objective Evolutionary Algorithm (DMOEA) [12] can be used to solve different optimization problems. However, other authors applied RCGA algorithm to optimize the linear array [13]. It is critical to simplify array thinning and reduce antenna weight. As a result, the synthesis of thinned planar arrays has gained increasing attention. Capon and Capon-like an estimation of the antenna array based on the arrival angles [14], ant colony optimization (ACO) [15] and the firefly algorithm [16]. On the other hand, due to the versatility of synthesis RCGA, GA is a promising global optimization approach. Hence, the proposed algorithm applies the mutation process that uses the power distribution as enhancement tool. To solve nonconvex optimization problems, well-known evolutionary algorithms (EA) and other nature-inspired methods have been successfully applied [17]. In this paper, the proposed real-coded GA issued as a constraint multi-objective evolutionary algorithm (CMOAE) to achieve better performance than other algorithms for following reasons: (i) The floating-point values used in RCGA is more rapid than the binary GA. (ii) RCGA minimizes the local minimum trapping possibilities because of the multipath mechanism of research in a parallel way. (iii) RCGA does not calculate the derivatives or other auxiliary functions that lead to RCGA optimizes the spaces, whereas the possibilities of finding high performance are high. The primary aim of this paper is to conserve power. This can be done by applying the RCGA to URA layout under the constraints of the array factor formula and regulating the SLL to achieve array

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efficiency running on FNBW. Hence, the complexity of synthesis the array factor is decreased.

The contributions of this paper can be stated as follow: (i) 24.4% of the energy consumption is saved by selecting the effective antenna elements that could be scrambled with high effectiveness. (ii) The optimization time is decreased because the author has divided the array area into subspaces. (iii) This paper conserves the SLL less than -20 dB. (iv) The value of FNBW is kept tenably. In terms of a cost function, advanced array synthesis problems are typically nonconvex optimization problem.

The remainder of the paper is organized as follows: In Section II, the mathematical model of the optimization problem is analyzed. In Section III, the RCGA algorithm with the cost function is proposed. In Section IV, The simulation results are analyzed and discussed. Finally, Section V concludes the paper.

II. Mathmatical Model Analysis

In this paper, the Array Factor (AF) used as a fitness function for thinning array to save the transmitted power based on turning-off some radiation elements and to control the side-lobe level to save the maximum radiation in the main lobe in high directivity as seen in Eq.1. The main reason for choosing the AF is that controlling the AF can increase the signal strength, hence, a high directivity is obtained. This leads to reduce the side lobes and to achieve high Signal-to-Noise ratio and high gain. This means the sent power wastage is controlled.

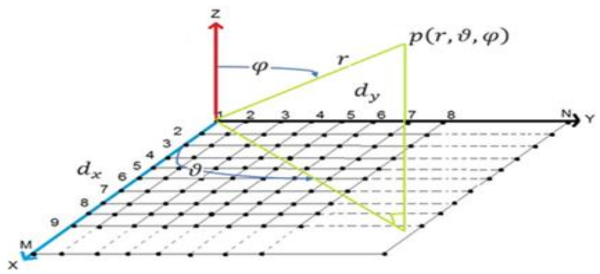


Fig. 1. Explains the M × N URA original geometry without thinning

In the general case, the AF for rectangular array, contains 40×40 elements.

$$\mathrm{AF} = \sum_{a=0}^{N-1} \sum_{b=0}^{M-1} I_{ab} e^{-j\pi\sin\vartheta(a\cos\varphi+b\sin\varphi)} \quad (1)$$

where I_{ab} are the amplitude weight values between [1,0] and the N and M are the array dimensions, ϑ *and* φ are the azimuth and elevation angles as seen in Fig. 1. For simplifying Eq.1, suppose $I_{ab} = [0,1]$ and the array dimensions M is set to be equal N. Hence, the summation formula can be written as shown in Eq.2:

$$\sum_{n=1}^{N-1} f^n = \frac{1-f^N}{1-f} \quad (2)$$

Therefore, by applying this summation twice, Eq.1 can be expressed as shown in Eq.3.

$$\mathrm{AF} = \left(\frac{1-e^{-jN\pi\sin\vartheta\cos\varphi}}{1-e^{-j\pi\sin\vartheta\cos\varphi}}\right)\left(\frac{1-e^{-jN\pi\sin\vartheta\sin\varphi}}{1-e^{-j\pi\sin\vartheta\sin\varphi}}\right) \quad (3)$$

Eq.4 can be obtained by simplifying Eq.3.

$$\mathrm{AF} = \left(\frac{e^{-jN\pi\sin\vartheta\cos\left(\frac{\varphi}{2}\right)}}{e^{-j\pi\sin\vartheta\cos\left(\frac{\varphi}{2}\right)}}\right)\left(\frac{1-e^{-jN\pi\sin\vartheta\sin\left(\frac{\varphi}{2}\right)}}{1-e^{-j\pi\sin\vartheta\sin\left(\frac{\varphi}{2}\right)}}\right)\times$$

$$\left\{\left(\frac{\sin\left(N\pi\sin\vartheta\cos\left(\frac{\varphi}{2}\right)\right)}{\sin\left(\pi\sin\vartheta\cos\left(\frac{\varphi}{2}\right)\right)}\right)\left(\frac{\sin\left(N\pi\sin\vartheta\sin\left(\frac{\varphi}{2}\right)\right)}{\sin\left(\pi\sin\vartheta\sin\left(\frac{\varphi}{2}\right)\right)}\right)\right\} \quad (4)$$

For easy plotting, the UV axis is described by Eq.5 and 6 respectively.

$$U = \frac{k_x\lambda}{2\pi} = \sin\vartheta\cos\varphi \quad (5)$$

$$V = \frac{k_y\lambda}{2\pi} = \sin\vartheta\sin\varphi \quad (6)$$

III. Proposed Genetic Algorithm

The GA is an optimization approach influenced by biological life's evolutionary mechanism. Since it is a straightforward approach that does not directly utilize the gradient of the target function, the GA can be effectively implemented to complex functions [18]. In 1992, H.J Holland established the GA as the computational family of the new evolution, the idea of GA based on biological science ideas, such as natural selection, genetic inheritance and sexual reproduction [19]. Haupt proposed the binary-coded GA in 1995, and after two years, it began to be used in single-phase nulling control [20], [21]. With the development of GA methods, a new term is announced as a Real-coded Genetic Algorithm (RCGA) using a floating-point value to present the real variables that is unrestricted for binary encoding and decoding with advantage of fast treatment [22]. For example, optimization of the linear antenna array set the real weights for radiation elements to reduce the max SLL in a Concentric Circular Antenna Array (CCAA) with a specified beam width restriction is suggested in [23]. As known, the Binary GA stages start with the parents. Therefore, the antenna power has two cases on and off symbolled by binary one and zero respectively. However, in Real coded GA, the parents have floating values between [0,1].The most important issues of GA are the following: (i) Selection procedure: the roulette wheel selection method is used as the calculated cumulative sum of the good values.(ii) Crossover step: this step is used to mate the parents to produce children (offspring), consequently, for parents production, the following sequence is used (Eq.7.):

$$x^{(1)} = \left(x_1^{(1)}, \ldots, x_{n-1}^{(1)}, x_n^{(1)}\right) \ldots x^{(N)} = \left(x_1^{(N)}, \ldots, x_{n-1}^{(N)}, x_n^{(N)}\right) \quad (7)$$

Hence, the children are produced in the following sequence (Eq.8.).

$$y^{(1)} = \left(y_1^{(1)}, \ldots, y_{n-1}^{(1)}, y_n^{(1)}\right) \ldots y^{(N)} = \left(y_1^{(N)}, \ldots, y_{n-1}^{(N)}, y_n^{(N)}\right) \quad (8)$$

In this paper, the Heuristic crossover operator (HX) for nonlinear constrained and non-constrained optimization problems is used [24, 25]. The HX operator as iterative and recursive procedure can be described in Eq.9.

$$y_i = \alpha\left(x_i^{(2)} - x_i^{(1)}\right) + x_i^{(2)} \quad (9)$$

where α is uniformly distributed between [0,1].

(iii)-Mutation methodology: In this stage, a new gene is created as a new population to maintain population diversity. For getting the mutation process, the power distribution is applied according to Eq.10.

$$f(x) = px^{(p-1)} \; where \; 0 \le x \le 1 \quad (10)$$

In present paper, the synthesis procedure is proposed for the decomposition of the rectangular array into a multi-linear array in horizontal and vertical directions, noting that I_{ij} is the intersected elements ,I_{ii} is the diagonal elements, and is $\frac{\lambda}{\sqrt{2}}$ the space between the two successive diagonal elements , in this way, a new step it is easily added to avoid the diagonal space difference using the differential evolution algorithm (DE).

Fig. 2 shows the flow chart of the proposed GA.

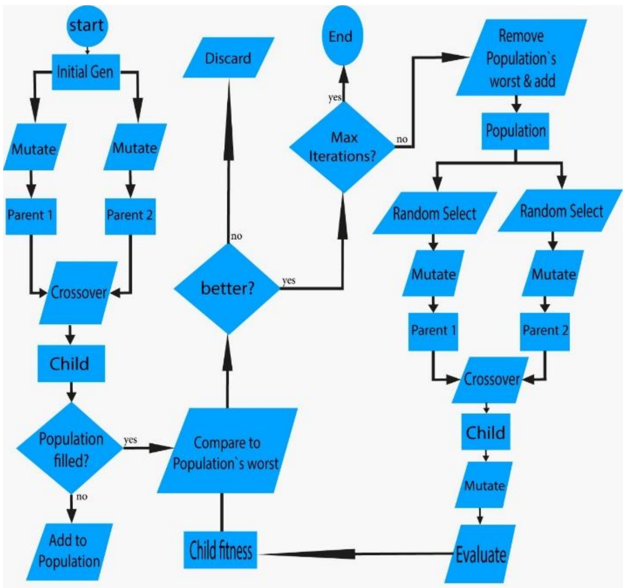


Fig. 2. Proposed GA flowchart.

Algorithm 1 describes the pseudo code of the proposed GA algorithm.

Algorithm 1. Genetic pseudo code

```
# Genetic pseudo code
BEGIN
INPUT(population, objective_fun, crossover_rate, mutation_rate, max_iterations, population_size, initial_genome)
gen1 ← Mutate(initial_genome)
gen2 ← Mutate(initial_genome)
population.add(gen1)
population.add(gen2)
for i ← 1 . . . max_iterations do
gen1 ← Random_Select(population)
gen2 ← Random_Select(population)
genchild ←crossover(gen1, gen2, crossover_rate)
genchild ← Mutate(genchild, mutation_rate)
if population.size < population_size then
population.add(genchild)
else
Sort_By_Fitness(population)
fitnessgenchild ← Evaluate_Fitness(genchild, objective_fun)
if fitnessgenchild > population.last.fitness then
population.remove_worst
population.add(genchild)
end if
end if
end for
END
```

The RCGA cost function is a minimization fitness function based on the amplitudes to save power and on the phases (azimuth and elevation) subject to the constraints of SLL values with a permitted change of FNBW. The cost function can be derived as (Eq.11)

$$\text{Fitness} = \max\left(20\log10 \frac{\text{AF}(\vartheta,\varphi)}{\max|\text{AF}(\vartheta,\varphi)|}\right) \quad (11)$$

$$\text{s.t.} \;\; \max \text{SLL} \le -20 \text{ dB and Variance(FNBW)} \le 2^{0}$$
$$Where, max|AF(\vartheta,\varphi)| = max|AF(\vartheta_0,\varphi)| \; for \; 0 \le \vartheta \le \pi$$
$$in \; the \; case \; of \; \vartheta \ne \vartheta_0 \; and \; -\pi \le \varphi \le \pi$$

IV. Simulation Results

In this paper, MATLAB CAD Ver. 2018a is used as a platform. The design of URA consists of 40×40 antenna elements under 26 GHz operating frequency and Bandwidth of 10% of center frequency. This means that λ=0.0115m.

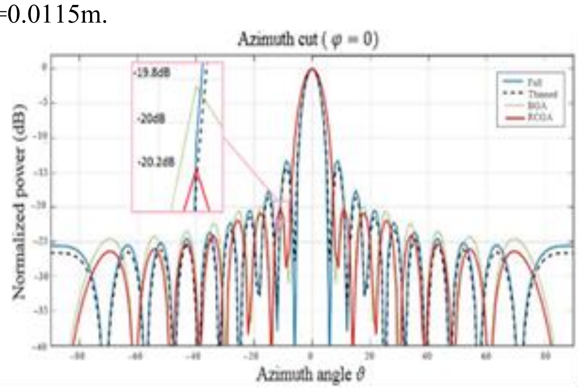


Fig. 3. Comparing between the URA, thinned URA with and without the Genetic algorithm.

It can be seen from Fig. 3. that the main lobe of all patterns is reached 0 dB. Furthermore, the constraints criteria of this graph plot stand on two issues max SLL and the FNBW variance. FNBW has defined standardly as the angular span between the first pattern nulls closed to the main lobe. Furthermore, the angular separation is calculated away from the main beam, which is drawn on the major lobe between the null points of the radiation pattern.

It can also be observed that the SLL in BGA is -19.84dB. Hence, this value does not satisfy the cost function constraint. However, in RCGA implementation the max SLL is -20.2 dB. Obviously, the FNBW in the cases of the full filled URA and thinned URA is the same FNBW = 11.2^o. However, the FNBW in BGA and RCGA is widening as 12^o and 12.8^o respectively. Because the used operating frequency is 26 GHz model so the FNBW=140 λ/D, this means that the effective length and the effective area of the BGA and the RCGA is different from the fullfilled URA, for this reason the FNBW is slightly wide.

Fig. 4. is divided into three geometrical planar arrays A, B, and C. Fig. 4A. shows the complete fullfilled antenna with 1600 antenna elements. Fig. 4B. explains the first population with different amplitudes represented as power. In this shape, the darkness steps from zero to one as a normalized power. Finally, Fig. 4C. explains the final RCGA array with a ratio of 75.6% power on elements. Therefore, the power saving percentage is 24.4%. Hence, this paper focuses on the last result of RCGA-URA.

A. Full filled *URA* B. Thinned URA C. RCGA-URA

Fig. 4. Geometry of 40x40 URA with (A) full –filled URA , (B)Thinned and (C) RCGA-URA.

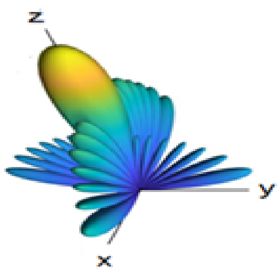
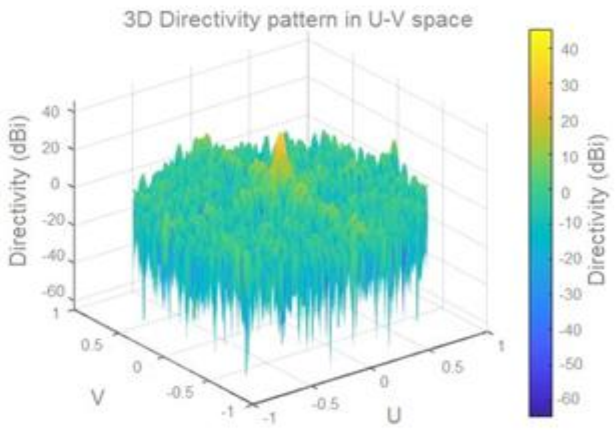


Fig. 5. The 3D array pattern geometry shape of the array in the XY axis in the direction of Z-axis using the Genetic algorithm

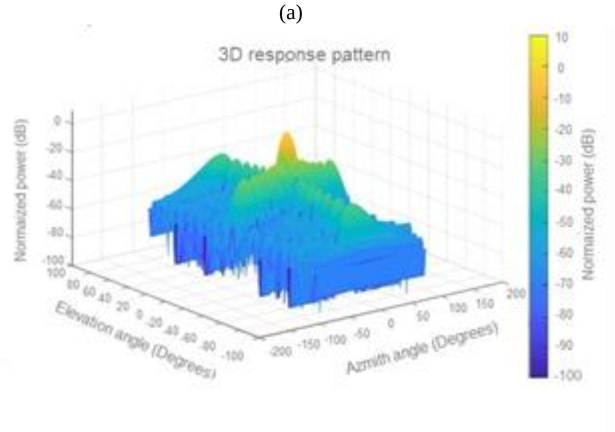
Fig. 5. shows the 3D array pattern geometry shape where the main-lobe clearly has the high directivity and both side-lobes and tail lobes have low power.

It can be shown from Fig. 5. that the concentrated transmitted power is located in the main lobe and the SLL is suppressed. Hence, the proposed RCGA can direct the transmitted power to get higher directivity. As a result, more power is saved (no waste power).

Fig. 6. presents a 3D power distribution in term of directivity of the array in both cases fullfilled URA and RCGA –URA. It can be seen from Fig. 6-a. that a lot of noise appeared and the power is distributed randomly. However, it can be noticed from Fig. 6-b. that the power distribution is more directive, and the power distribution is more systematic. Furthermore, the side lobes are clearly seen by low power distribution which means that using the RCGA is more beneficial geometrically.



(a)

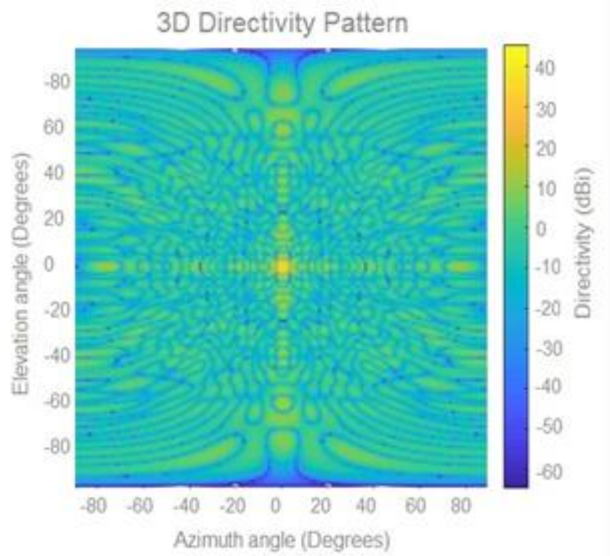


(b)

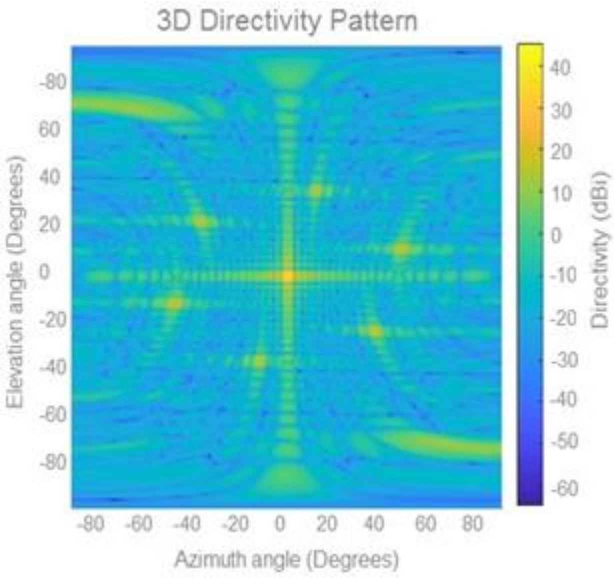
Fig. 6. The 3D directivity pattern responses in rectangular coordination (a)-U-V coordinates for Full-filled URA (b)-RCGA-URA but in degrees.

Fig. 7. shows the distribution of power for fullfilled URA and RCGA-URA in the 2D representation. It can be seen from Fig. 7. that the power distribution in the fullfilled URA is stochastically distributed. This means that the power of side lobes is high, and the range of transmission distance is less than the RCGA-URA. It has been noted that the power distribution presented by the directivity is more systematic. . Hence, the power distribution over RCGA URA can be used in hand gesture application which needs soft motion [26].Moreover, the dirctivity distibution shown in Fig. 7. is considered to be one of state of the art contributions of the paper. This paper achieved superior results which are much better than those achieved by the modified binary coded genetic algorithm in [27], especially, in terms of saving power and the

number of radiation elements. In addition , the proposed algorithm produced better outcomes than those proposed in [6] in terms of the first fast forier transform SLL and the number of elements square planar array.



(a)



(b)

Fig. 7. The 3D directivity pattern responses in rectangular coordination (a)-U-V coordinates for Full-filled URA (b)-RCGA-URA but in degrees.

V. Conclusion

The power in the physical layer of communication systems has been saved with a 24.4% using the proposed RCGA algorithm. Furthermore, the array's directivity has been improved by the selection of 1210 effective radiation elements. In addition, the maximum side lobe level has been reduced to -20.2dB in terms of power scale normalization. The numerical results has indicated that the proposed method can reduce the side lobe level of the thinned array by at least 1.3dB deposit of existence of 100 elements in a planar array, These elements are spaced greater than half wavelength and their locations are optimized using the differential evolution. Evolutionary Algorithm as an artificial intelligence tool helps to control the FNBW which is very important to get a high resolution of the array pattern. The proposed algorithm had led the FNBW to be 11.2^{o} and the variance not exceed 2^{o} from the fullfilled URA FNBW. In the future work, the evolutionary algorithm for non-uniform areas may be used as an adaptable tool between elements to maximize the used energy when standing at different positions.

Conflict of Interest

The author Declares no conflict of interest.

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