Comparing the Failure Correction Ability between GA and FA for Array Antenna

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Abstract—**Array antenna may be damaged due to the external environment, and the performance of the array will greatly be decreased because of elements failure. In this paper, the effect of elements failure on equispaced linear array pattern based on uniform weighting and two typical beamforming methods is analyzed. If elements failed during operation, significant degradation in the array's performance is obtained. And then, two optimization algorithms were implemented by re-optimizing the weighting coefficients of the non-failed elements to mitigating the influences of the radiation pattern. We investigated the response of the algorithm to redistribute the excitation of remained elements by which parameters and similarity rate of array pattern obtained when elements failed. Finally, the simulation results show that two algorithms can be used to compensate the side lobe level and null depth level of the pattern when the elements are failed in an array. Furthermore, the performance obtained by using Firefly Algorithm is better than Genetic Algorithm under the same iteration.**

Keywords—linear array pattern; elements failure; firefly algorithm; genetic algorithm

I. INTRODUCTION

An antenna array is composed of many elements whose excitation amplitude and phase can be individually adjusted to yield the desired pattern. As the number of components increases and operating time to be prolonged, the probability of failure of antenna elements in the array increases. The damaged array will result in distortion of the array antenna pattern, which affects the normal use of the array antenna. Many methods have been investigated for correcting array pattern when elements defected. A study on the effect of an element failure to an array's radiation patterns, with respect to the probability of failure, is performed in [1], and it is shown that mitigation of failure effects is possible if the possibility of failure is taken into account during early design stages. The iterative Fast Fourier technique to array failure correction with the placement of single wide nulls and dual wide nulls while keeping the side lobe level to its minimum value is presented in [2]. A genetic algorithm (GA) based technique is proposed, and the design of a dual-band antenna array, with the ability to remain fully functional after one element failure is presented in [3]. Adaptive genetic algorithm (AGA) change the excitation of elements to improve the performance of an array with failed elements is proposed in [4]. An improved particle swarm optimization (PSO) algorithm is proposed for the fast array failure correction in digital beam-forming of arbitrary arrays in [5, 6]. The problem of antenna array failure has been addressed using Firefly Algorithm (FA) by controlling only the amplitude excitation of array elements in [7]. Only the inter-element spacing's between the elements are adjusted using Differential Evolution (DE) algorithm to regain the pattern closed to the original one is proposed in [8] in presence of the failure of array elements. A metaheuristic approach based on PSO and bacteria foraging optimization (BFO) algorithms to optimize the array excitations with a priori knowledge of failed elements in the array is described in [9]. The meta-heuristic cuckoo search algorithm (CSA) is used in [10] for the suppression of side-lobes level and steering of nulls at their required positions in the failed array antenna.

In this article, two optimization algorithms were implemented by resynthesizing the excitations of the remaining elements to maintaining the radiation properties. The algorithms based on metaheuristics are called GA and FA. Both algorithms can reduce the Side Lobe Level (SLL) and recovery the null steering of the radiation pattern effectively in failed antenna arrays. We compared the performance of the two algorithms in correcting the radiation pattern of the damaged array and found that the Firefly Algorithm is better than the Genetic algorithm in optimizing the radiation pattern.

II. INFLUENCE OF ELEMENTS FAILURE

The elements of the large array are all working normally under ideal conditions. However, the damage of array elements can't be avoided due to the external environmental impact or the loss of internal components. The array failure will directly change the aperture distribution of the array antenna, resulting in the SLL raised, the gain decreased, and make the First Null Beam Width (FNBW) and Half-Power Beam Width (HPBW) broad, which seriously affect the normal use of the array antenna. This section analyzes the effect of array failure on the equispaced linear array based on uniform weighting and two typical beamforming methods.

With the number of failed elements increase, the performance of the array deteriorated sharply, and it will make the adaptive beamforming algorithms failed when the condition is worse. The formula for calculating the pattern under the N elements uniform linear array (ULA) is that:

$$F(\theta)=\sum_{n=0}^{N-1} w_n \exp\left(j\frac{2\pi}{\lambda} nd \sin\theta\right) \quad (1)$$

When N = 8, we use linearly constrained minimum variance (LCMV) to synthesize linear array pattern, and method was studied on random elements failure in the antenna array. We get null steering at 45° by use of LCMV, The results are shown in Figure 1.

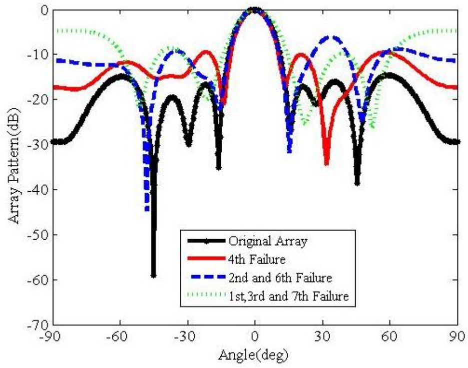


Fig. 1. Array pattern failure when N=8.

III. Pattern Correction

The cost function of the algorithm, under normal and failure conditions is defined as:

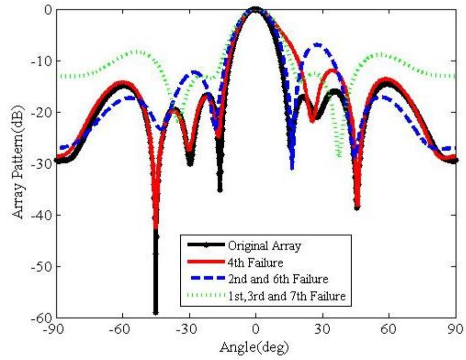
$$C=\begin{cases}\mu_A\left[F_A(i)-F_A^C(i)\right]^2+\mu_B\left[F_B(i)-F_B^C(i)\right]^2+\mu_C\left[F_C(i)-F_C^C(i)\right]^2\\ \mu_A+\mu_B+\mu_C=1\end{cases} \quad (2)$$

$$\underset{w}{Minimize} \quad C$$
$$subject \quad to \quad T^H w=0 \quad (3)$$

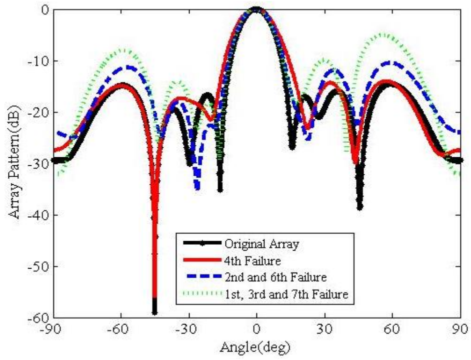
Where $F_A(i)$, $F_B(i)$ and $F_C(i)$ are values of the sample point in normal array pattern at a different range of angles. $F_A^C(i)$, $F_A^C(i)$ and $F_C^C(i)$ are values of the sample point in corrected array pattern at a different range of angles under failure conditions. μ_A , μ_B and μ_C are the weighting coefficients of the range, which represent the importance of the different regions on the pattern. Adjusting the values of μ_A , μ_B and μ_C can make the corrected pattern closer to the original pattern in the main lobe, side-lobe, and null depth. w is the weight vector of the array excitation, and T^H is the matrix of the probability failure element. To compare the performance of the GA and FA for re-optimizing the pattern, we set the same number of populations and iterations for the two algorithms, which are 500 and 2000 in this paper, respectively. Two algorithms are applied to compensate array pattern by redistributing the weights over the remaining elements when element failures occur in this paper. The failure array pattern is re-optimized by using GA and FA respectively.

A. Pattern repair

The result of 8-elements linear array pattern correction under the premise of corruption with several of number and position are shown in Figure 2. From the figures, we can see that two algorithms are perfect for the repair of Maximum SLL and Null Depth Level (NDL) when only one element fails. However, the correction of two algorithms on the pattern is not significant and the effects of array failure are still conspicuous as the number of failure elements increases.



(a)

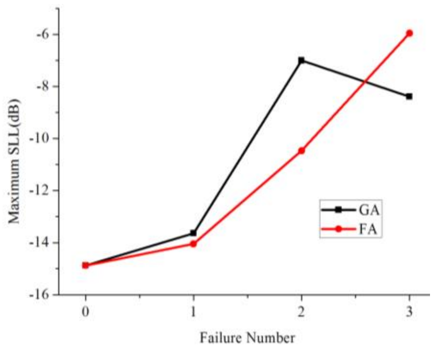


(b)

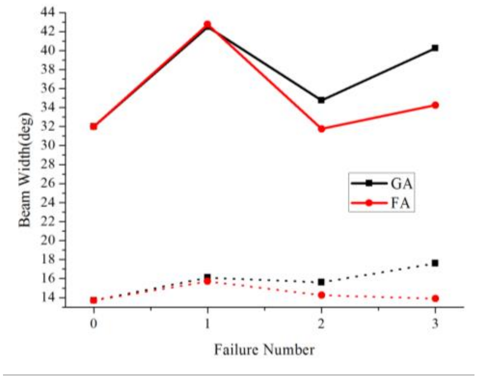
(a) Array pattern corrected by GA when N=8; **(b)** Array pattern corrected by FA when N=8.

B. Parameters repair

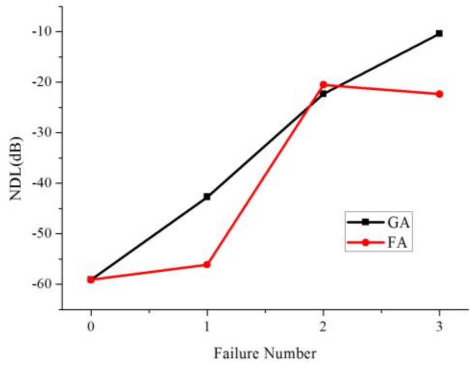
Figure 3 shows the comparison of four parameters using two algorithms to re-synthesize the array pattern suffered by elements failure. From these figures, we can see that the indexes of Maximum SLL, FNBW, HPBW, and NDL are recovered to some extent, but the optimization results deteriorated as the number of failed elements increases of the array. In addition, it can be seen from the figures that the FA performs better than the GA to correct the array pattern when N=8. Because algorithms sometimes have instability, GA performs better in terms of maximum SLL at failure number=3.



(a)



(**b**)



(**c**)

Fig. 2. (**a**) Maximum SLL compensated when N=8; (**b**) Beam Width compensated when N=8 (solid line: FNBW; dotted line: HPBW.); (**c**) NDL at -45°compensated when N=8.

C. Comparing the Ability between GA and FA

To evaluate the scale of the array pattern when elements failed and corrected, a similarity rate function was introduced. The function is defined as

$$SR = 1 - \frac{\sum_{i=1}^{N}\left[F(i) - F'(i)\right]^2}{\sum_{i=1}^{N} F^2(i)} \tag{4}$$

Where $F(i)$ is the value of sample point in a normal array pattern, and $F'(i)$ is the value of sample point in failed or corrected array pattern.

Figure 4 shows the similarity rate between the original pattern and the patterns re-synthesize by GA and FA for the 8-elements array. It can be seen that the original pattern has a large difference from the pattern after elements failure, which indicates that failed elements have a greater impact on the array performance, and this influence is amplified with the number of failed elements increase. The simulation results show that the two algorithms can improve the similarity between original pattern and the pattern when the elements defected, and it explains that GA and FA can be used to repair the array pattern when there are element fails in the array. In addition, from the figure, it can be concluded that the rate of similarity obtained by using FA is better than GA under the same iteration.

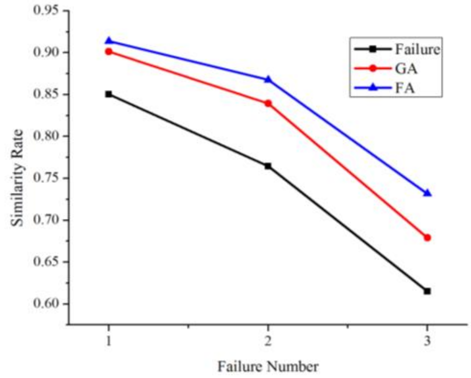


Fig. 3. Array pattern similarity rate corrected when N=8.

IV. CONCLUSIONS

In this paper, the effect of elements failure on the array pattern is analyzed, and the corruption of pattern is obtained when elements failure in different numbers and positions. Two optimization algorithms were implemented by re-optimizing the weighting coefficients of the non-failed elements to mitigating the influences of radiation pattern when elements defected in the array. The simulation results show that the GA and FA can be used to compensate the Maximum SLL and NDL of the pattern when there are element fails in the array. However, significant degradation in the array's performance is observed when elements failed during operation, even after the redistribution of the excitation coefficients of the remaining elements. By comparing the optimization results of the two algorithms, we get that performance obtained by using FA is better than GA under the same iteration. In addition, the two algorithms can also be generalized to any array antenna systems such as planar arrays and circular arrays.

ACKNOWLEDGMENT

This paper is funded by the International Exchange Program of Harbin Engineering University for Innovation-oriented Talents Cultivation. This work was partially supported by the National Key Research and Development Program of China (2016YFE0111100), Key Research and Development Program of Heilongjiang (GX17A016), the Science and Technology innovative Talents Foundation of Harbin (2016RAXXJ044), the Natural Science Foundation of Beijing (4182077) and China Postdoctoral Science Foundation (2017M620918).

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