An Improved Method of Diagnosis of Failed Elements in Arrays Using Genetic Algorithm

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Abstract— A cost function was used to compare the calculation pattern (associated to the chromosome encoded by GA) with the degraded pattern at the samples measured from the far field radiation pattern. Genetic algorithm was used to minimize the cost function to locate the failed elements. However, it was found that when using GA to diagnose the failed elements in an array, this method could not accurately distinguish symmetrical positions if the excitation of the arrays were symmetrical. In order to solve this ambiguity problem, an asymmetry factor was introduced in the mentioned diagnosis method to the excitation distribution (amplitude or phase) of the arrays artificially. This improved method was exploited to a linear array to validate the method. From the comparison between the symmetrical and asymmetrical excitation distributions of the arrays, it was showed that the improved method was applicable. And weight coefficients were introduced in the cost function in order to get better results.

1. INTRODUCTION

Diagnosis of the failed elements of an array was a problem of practical interest, especially in the large-scale antenna arrays [1]. Array antennas were working in the applications such as trace tracking, position locating, and communications and so on. The antenna, in such cases, had a lot of radiating elements, and the failure possibility of the elements increased due to the large number of radiators. These failed elements made the sidelobe level increased and caused unacceptable pattern distortion. With the failed elements been found in the array, the radiation pattern can be restored by changing their feeding distribution [2–5].

Artificial neural network (ANN) technique has been used for finding out the position of the fault element(s) in the array in [6], a neural network (MLP) is used to locate a maximum of three failed elements in a 16-element array, in [7], Also using the MLP ANN locate a maximum of two failed elements in a 6×6 microstrip patch antenna array. Nan Xu using the SVM (support vector machine) classifier for failure detection in a 4-element array [8]. A solution to locating the position of the fault element(s) in the array reported in [9] using genetic algorithms (GA). In that, using a cost function, the method compares the measured radiation pattern with that corresponding to the array with a given configuration of failed/un-failed elements. However, this method could not accurately distinguish symmetrical positions if the excitation of the array was symmetrical.

In order to solve this ambiguity problem, an asymmetry factor was introduced in the mentioned diagnosis method to the excitation distribution (amplitude or phase) of the arrays artificially. And weight coefficients were introduced in the cost function in order to get better results.

2. IMPROVED DIAGNOSIS METHOD

When there are failed elements in the antenna array, it would lead to changes in the far field pattern, particularly the side lobe level. And different numbers and the locations of the failed elements in the array will make different pattern distortion.

In this paper, each of the elements was assumed to have one of the two states, that were, states "On" and "Off". In state "On", the element worked properly, and in state "Off", the element does not work at all [10]. As a theoretical study, the simulation result from HFSS was considered as the result obtained from the experiment.

Let us consider a linear array of N identical elements. The far field electrical field can be calculated with the following expression

$$E(\theta, \varphi) = f(\theta, \varphi) \cdot \sum_{n=1}^{N} I_n \cdot \exp(jnkd\mu) \tag{1}$$

where $f(\theta, \varphi)$ is the element pattern, I_n is the vector of the excitation of the N elements. $\mu = \sin\theta \cdot \cos\varphi$, The far field directivity of the array expressed in dB was:

$$F(\theta, \varphi) = 20 \cdot \log_{10} |E(\theta, \varphi)| \tag{2}$$

Encoding the configuration of I_n, we define the following cost function:

$$\xi = \sum_{i=1}^{M} \omega_k \cdot \left[\overline{F_{chr}}(\theta_i, \varphi_i) - \overline{F_M}(\theta_i, \varphi_i)\right] \tag{3}$$

M is the number of samples we selected. $F_M(\theta_i, \varphi_i)$ is measurement of the degraded pattern in M directions (θ_i, φ_i), $F_{chr}(\theta_i, \varphi_i)$ is the amplitude pattern Calculated by (1) and (2) associated to the chromosome in the same direction. Where $\overline{F_{chr}}(\theta_i, \varphi_i)$ and $\overline{F_M}(\theta_i, \varphi_i)$ are the normalized pattern date of $F_{chr}(\theta_i, \varphi_i)$ and $F_M(\theta_i, \varphi_i)$. ω_k was the weight coefficient, we can get better results by change the weights. With the weight coefficient introduced can avoid a parameter change range too large overwhelmed the contributions of other parameters of the cost function. Genetic algorithm was used to minimize the cost function that compared the calculation pattern (associated to the chromosome encoded by GA) with the degraded pattern at the samples.

However, it was found that when using GA to diagnose the failed elements in an array, this method could not accurately distinguish symmetrical positions if the excitation of the array was symmetrical. Because the pattern calculated $F_{chr}(\theta_i, \varphi_i)$ associated to the chromosome is the same if the failed elements were at symmetrical positions when the excitation of the array was symmetrical.

In order to solve this ambiguity problem, an asymmetry factor was introduced in the mentioned diagnosis method to the excitation distribution (amplitude or phase) of the arrays artificially. This improved method was exploited to a linear array and validate the method. From the comparison between the symmetrical and asymmetrical excitation distributions of the above two arrays, it was

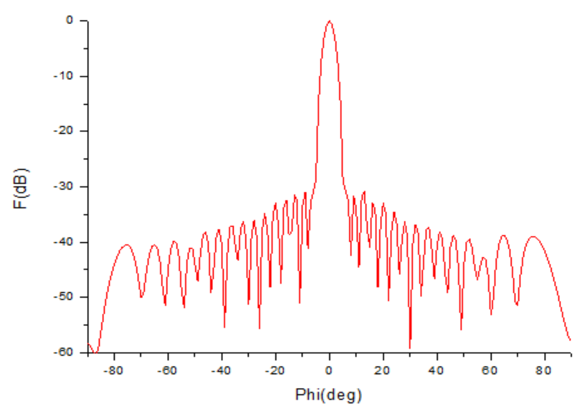

Figure 1: Linear Taylor pattern radiated by the 32 elements array of $\lambda/2$-dipoles with no failures.

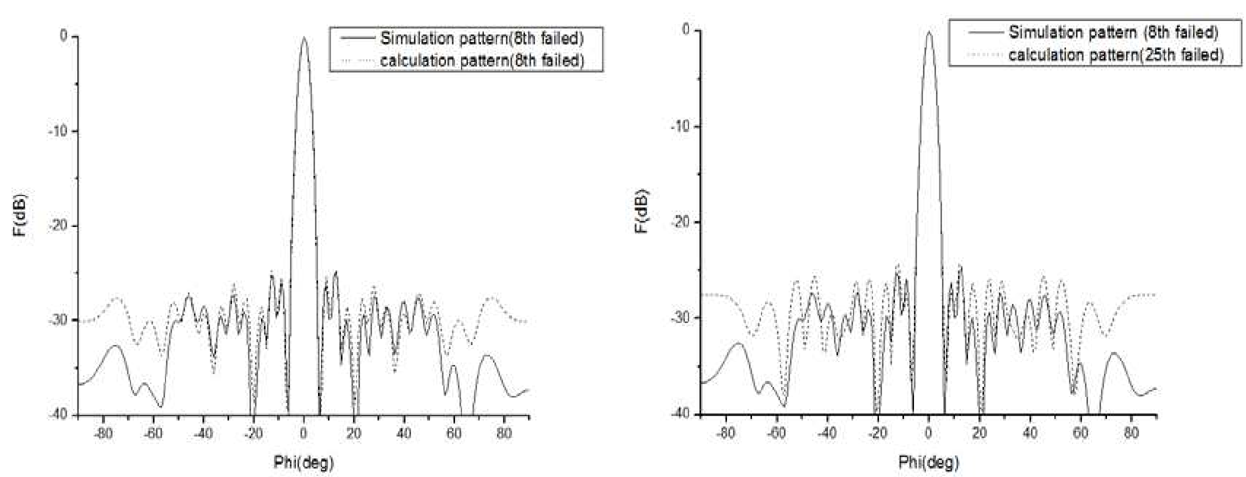

Figure 2: Simulation pattern and calculation pattern (8th was failed/25th was failed) when excitation amplitude was changed.

showed that the improved method was applicable.

3. ANALYSIS AND APPLICATION

We study a linear array composed of 32 center-fed cylindrical $\lambda/2$-dipoles. The pattern, which is shown in Figure 1, has been emulated by a linear Taylor distribution with $SLL = -30\,\text{dB}$ and $d = \lambda/2$ using HFSS.

An asymmetry factor was introduced to the arrays by change excitation distribution (amplitude or phase) of a element artificially. For the selected array elements which need to be changed, change the element excitation closed to the center of the array will get further damage to the degraded pattern; however the effect was too small if change the element excitation in the edge of the array which was easily be overwhelmed by measurement error. So in this article, we select the 5th element as the one which need to be changed. And the method was verified by change the excitation amplitude and phase of the 5th element respectively.

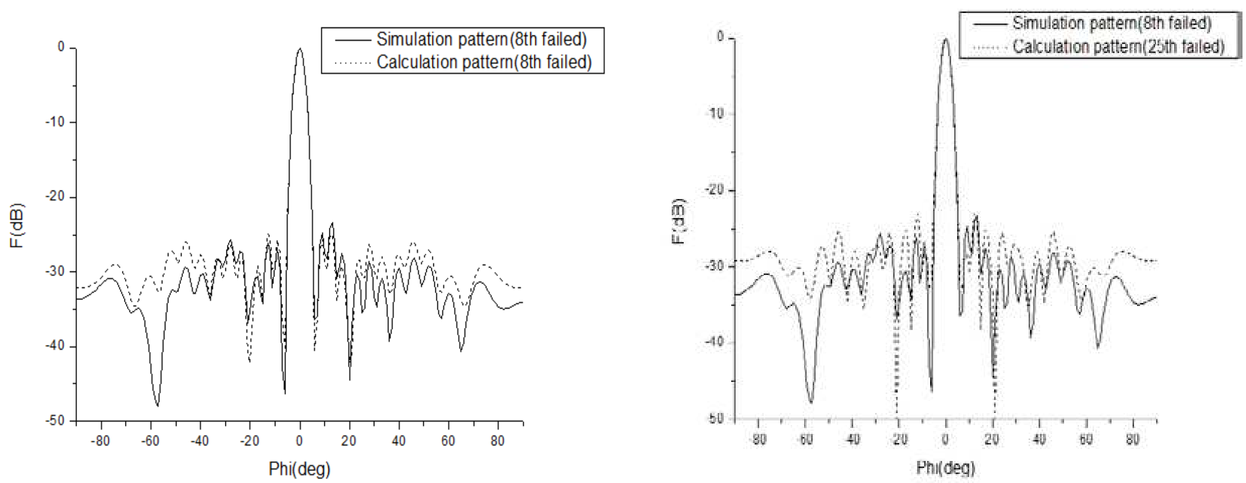

Figure 3: Simulation pattern and calculation pattern (8th was failed/25th was failed) when excitation phase was changed.

Table 1: Performance of genetic algorithm diagnosis of array failed elements when changed the excitation amplitude and phase of the 5th element respectively. Δ was the random measurement error.

25 pattern samples $\Delta = \pm 0.75\,\text{dB}$				
Failed elements positions	Success rate (change the amplitude/change the phase) ω_k was introduced		Success rate (change the amplitude/change the phase) without ω_k	
	change the amplitude	change the phase	change the amplitude	change the phase
5	10/10	10/10	10/10	9/10
8	10/10	10/10	10/10	10/10
15	10/10	10/10	10/10	10/10
28	10/10	10/10	10/10	10/10
3, 10	10/10	10/10	9/10	8/10
5, 25	10/10	10/10	9/10	7/10
9, 31	10/10	10/10	8/10	8/10
4, 18	10/10	10/10	9/10	8/10
6, 10, 16	9/10	9/10	7/10	6/10
3, 8, 20	9/10	8/10	7/10	5/10
7, 9, 18	10/10	9/10	7/10	5/10
1, 5, 32	8/10	7/10	4/10	3/10
Total	116/120	113/120	101/120	93/120

1. Reduced 3 dB the amplitude of the excitation of the 5th element.
2. Reduced 22.5° the phase of the excitation of the 5th element.

The 8th elements were set failed in the HFSS models. Figure 2 showed the different between the simulation pattern and calculation pattern (8th was failed/25th was failed which was the symmetrical element of 8th element) when reduced 3 dB the amplitude of the excitation of the 5th element. And Figure 3 showed the different between the simulation pattern and calculation pattern (8th was failed/25th was failed which was the symmetrical element of 8th element) when reduced 22.5° the phase of the excitation of the 5th element.

From Figure 2 and Figure 3, by changing either the excitation amplitude or phase of 5th element will break the symmetry and solve the ambiguity problem when using Genetic Algorithm to diagnosis of failed elements in arrays.

In our study 4 random excitation distribution configurations were selected for each of the 3 conditions, they were, one element failed, two failed, and three failed. Each of the configurations was calculated ten times using GA. In our study, the test patterns were sampled in the region $\phi \in [-45, 45]$ and avoid the angle where the pattern amplitude is too small or difficult to measure. We raised the weight of samples at the main beam and side lobe, and decreased the weight of the samples with the increasing of the angle away from the main beam.

From Table 1, the performance of genetic algorithm diagnosis of array failed elements by changed the excitation amplitude and phase of the 5th element respectively were showed above. Diagnosis of failed elements in symmetrical array can be achieved. And by introducing weight coefficients into the cost function can get better results (even take random measurement error account).

4. CONCLUSION AND FUTURE WORK

An improved method of diagnosis of failed elements in symmetrical arrays using genetic algorithm through introducing asymmetry factor to the symmetric excitation arrays by change a certain element's excitation amplitude or phase. Failed elements can be found in symmetrical arrays. And weight coefficients were introduced in the cost function in order to get better results. Finally through a number of numerical examples shows the effectiveness of the method by simulation and calculation. The proposed method can be directly applicable to planar arrays. In the future the mutual coupling between radiating elements should be taken into account.

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