Adaptive Genetic Algorithm for Damaged Beam Pattern Re-synthesis of Active Phased Array

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1. Introduction

Array beam pattern is distorted when the transmitter and receiver module's (TRM's) malfunction occurs as time goes on. Degradations of solid state devices, semiconductors, integrated circuits and RF circuits, or changes in the characteristics of active devices deteriorate the performance of an entire system [1], [2]. The degradation of the TRM performance distorts an original beam pattern. That is side lobe level (SLL) increasing. The increased SLL of the beam pattern degrades performances of the entire system. Therefore, re-synthesizing the optimal beam pattern is essential for improving performances of the entire system.

Several studies have been reported on TRM failure compensation methods for re-synthesizing the optimal beam pattern. Peters [3] proposed a conjugate gradient method to re-configure the amplitude and phase distributions. The method involves calculating the sum and difference of the beam pattern of each element. Rodriguez [4] proposed array failure correction for planar arrays by simulated annealing technique and Lozano [5] reported the damaged beam pattern compensation with fixed nulls. Yeo [6] described an approach based on a genetic algorithm. Various mating schemes for a genetic algorithm were examined. Rodriguez [7] also applied a genetic algorithm for recovering the pattern by changing the excitation of some of the array elements. While approach utilizing a genetic algorithm is simple and useful, a faster and more accurate method is required for practical applications.

This paper proposes a method for re-synthesizing the optimal beam pattern from the damaged beam pattern using adaptive genetic algorithm based on a beam pattern mask. The re-synthesized beam pattern was produced by a computer simulation. It showed well-matched results within the desired beam pattern mask. The proposed method allows increased calculation speed with improved accuracy.

In this study, the proposed method is implemented with the appropriate specifications for realistic situations. We assume that the amplitude and phase distributions were quantized to 6 bits for computer simulations. The Chebyshev beam patterns are examined utilizing the proposed algorithm. Section II presents details of the proposed adaptive genetic algorithm; Section III provides the results and discussions of the proposed algorithm; and Section V gives conclusions.

2. Adaptive Genetic Algorithm

Fig. 1 shows a flowchart of the proposed adaptive genetic algorithm for damaged beam pattern re-synthesis method. During the operation of an array antenna system, TRM malfunctions can occur at any time. When TRM errors are detected, the corresponded TRM is supposed to be turned off. The re-calculation of amplitude and phase distributions with remaining TRMs by a genetic algorithm is then performed to fit the damaged beam pattern into the beam pattern mask. The array factor (*AF*) for N isotropic elements is given as

$$AF = \sum_{n=1}^{N} a_n e^{j\{(n-1)kd\cos\theta + \beta_n\}} \quad (1)$$

where a_n represents the amplitude excitation coefficients of the n-th element, k is the wave number, d is the array element spacing, θ is the radiating angle, and β_n is the absolute phase of an excitation. To reduce the SLL of the damaged beam pattern which is the excess SLL over the desired beam pattern mask, the fitness function for any angle i of the each iteration for a genetic algorithm is defined as

$$f_i = \left\{ A_{region\_m} \cdot \left(AF_{damaged,i} - mask_{outer,i} \right) \right\}^{-1} \tag{2}$$

for the beam pattern over the mask, where A_{region_m} is a weighting of each regions. m is the region number of the beam pattern mask and the region is divided into seven regions in this experiment. With this proposed fitness function for a genetic algorithm, the desired beam pattern will be re-synthesized to a suitably designed mask during the iterations.

For the advanced optimization for the desired beam pattern re-synthesis, we developed the adaptive genetic algorithm with the A_{region_m}. A genetic algorithm has numerous iterations to reach an optimal solution. The total iterations can be divided into several sub-iterations. At every sub-iteration, the algorithm calculates the average excess level (*AEL*) of the divided regions. The *AEL* is given by

$$AEL = \frac{1}{l} \cdot \sum_{\substack{\text{i of side} \\ \text{lobe sections}}} \left(AF_{damaged,i} - mask_{outer,i} \right) \tag{3}$$

for the beam pattern over the mask, where l is the number of angles of damaged beam exceeded the mask for each side lobe region. The weightings, A_{region_m}, of an initial iteration are set ones for the side lobe regions. Whenever the calculation meets sub-iterations, weighting one is adaptively added to the relative region which has the largest value of the *AEL*. The used initial beam pattern assumed is the Chebyshev pattern with a half power beam width (HPBW) of 4.2° and a flat SLL of -20 dB and the beam pattern mask is also designed. The applied array has 18 elements with the 6th TRM is assumed to have failed. The realistic quantization level is 6 bits for digitally adjusting amplitudes and phases. The minimum amplitude and phase step sizes are 0.5 dB and 5.625° for 6 bit controllable devices. The divided regions are indicated in Table I. Fig. 2 shows the beam pattern of the initial and first sub-iteration. The shadowed region exceeded the beam pattern mask indicates an excess level. The (II) and (VI) regions take additional weightings. These processes are repeated and finally reach an optimal solution. Table I shows the final adaptively applied weighting ratios of the divided regions. Fixed zero coefficient ratios are applied to the region (III) and (V), which are transition regions for flexible variation, and one to (IV) for the main lobe regions. Accordingly, the proposed method yields fast convergence speed, and highly accurate solution.

3. Results and Discussions

Fig. 3 shows the results of the proposed method when the 6th element failed among the total 18 elements. Newly calculated amplitudes and phases are set, and the radiation patterns are shown in Fig. 3. The result shows good agreement with the desired beam pattern mask. Table II shows the changes in the average excess level and half power beam width (HPBW). The re-synthesis leads to a decrease of the *AEL*, but HPBW is slightly increased, which could be considered a trade-off by reducing the SLL.

The calculation time of the proposed algorithm, which is the convergence time for the genetic algorithm, is faster than that when employing the genetic algorithm to re-construct the pattern to the original pattern, not using a beam pattern mask and proposed method. The proposed method can easily satisfy the convergence condition. As shown in Table II, the HPBWs were slightly increased, but time of the 1% relative convergence rate dropped to a third of that with the previous genetic algorithm [6]. Thus, the proposed algorithm is useful for reducing the SLL and even the convergence time.

4. Conclusion

In this work, a method for TRM failed beam pattern re-synthesis in an array antenna system has been developed. The proposed method uses the adaptive genetic algorithm for re-synthesizing the optimal beam pattern from the damaged beam pattern. The method has advantages including good accuracy, and faster calculation speed than that in previous study. The proposed algorithm thus provides a cost-effective and less time consuming solution for the active phased array antenna systems.

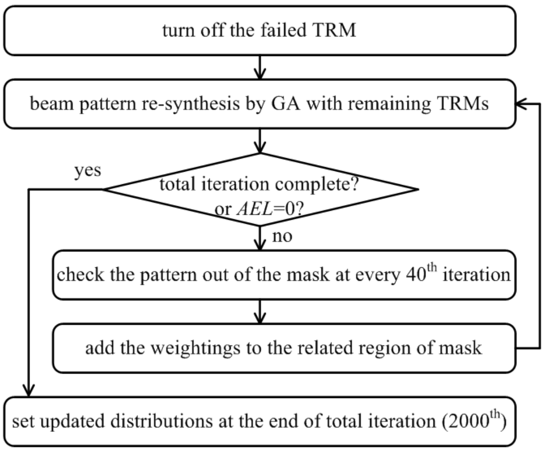


Figure 1: Flow chart of the proposed adaptive genetic algorithm for damaged beam pattern re-synthesis

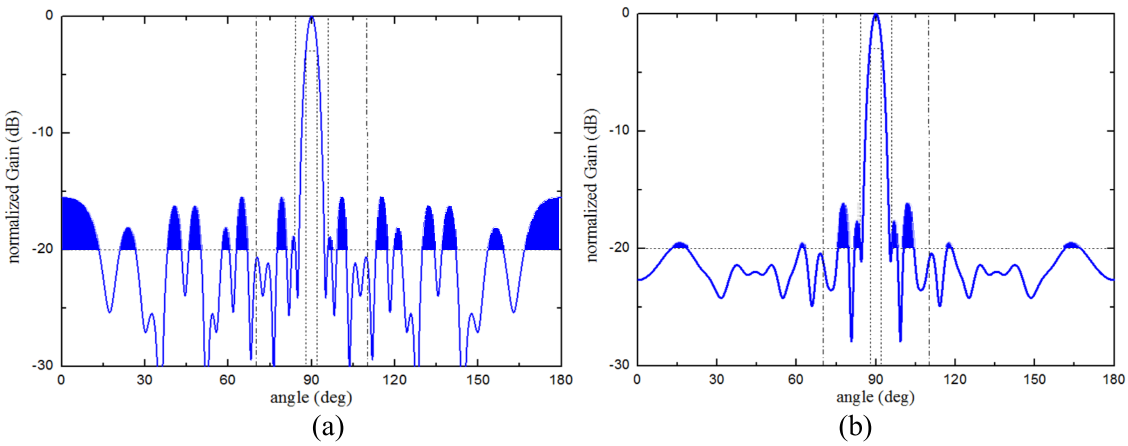
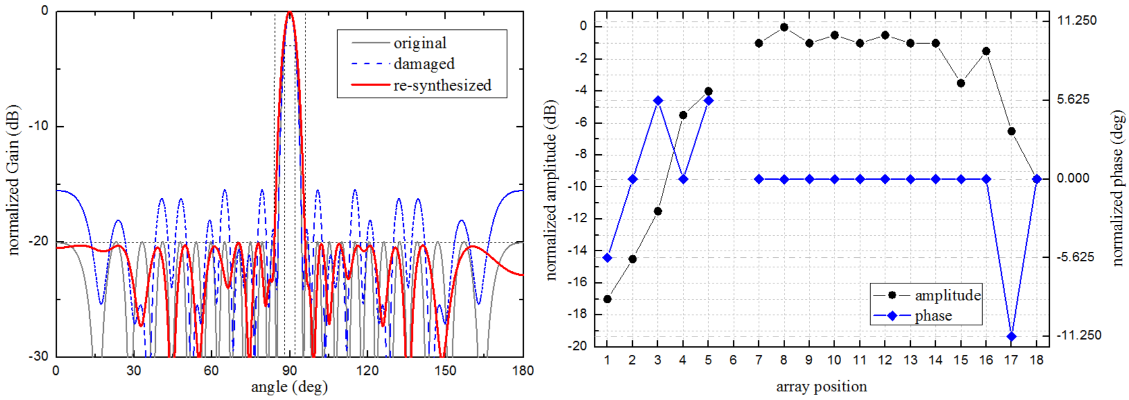


Figure 2: Progress of proposed algorithm for adaptive genetic algorithm. The shadowed region outside the outer mask is an error. (a) initial and (b) sub-iteration's pattern over total iteration.

TABLE 1: WEIGHTINGS OF EACH REGIONS OF MASK FOR CHEBYSHEV BEAM PATTERN

region(m)	I	II	III	IV	V	VI	VII
degree(i)	0~70	~84	~87.9	~92.1	~96	~110	~180
A_{region_m}	3	15	0	1	0	15	3



(a) (b)

Figure 3: Re-synthesizing results; (a) normalized gains for original Chebyshev, 6th TRM failed and re-synthesized beam pattern for 18 elements array. (b) re-calculated normalized amplitude and phase distributions.

TABLE 2: CHANGES OF THE *AEL* AND BEAM WIDTH FOR 6TH TRM FAILED

beam pattern	initial	damaged	re-synthesized
AEL	0 dB	2.62 dB	0 dB
-3dB BW	4.2°	4.2°	5.1°

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