A Healing System for Failed Antenna Array using PSO

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Abstract

In large antenna arrays possibility of getting faults for some of the radiating elements can not be denied at all the times. In such situation the pattern of the array gets distorted mostly with an increasing sidelobe level (SLL) and removal of the nulls, if any, from its desired position. In this paper a healing system using particle swarm optimization (PSO) is developed for these failed antenna arrays. Reconfiguration of the amplitude and phase distribution of the remaining working elements in a failed array can improve the SLL and also maintain the null position. The main purpose of using the PSO technique is its ease of implementation. Compared to its other counterparts, the PSO algorithm is simple, easy to code and a high performance computational technique.

1. Introduction

Antenna arrays have been used in mobile, wireless, radar communication and in many signal acquisition applications. In active antenna array to obtain a desired radiation pattern with specified sidelobe level, null steering and beamforming is possible by controlling the current excitations of individual elements of the array and also by optimizing the array geometry [1]. Different analytical and numerical methods are available to obtain the optimum values of the amplitude and phase of each array element and the array geometry for getting desired SLL and to obtain a null in prescribed direction [2-5]. But in situations, where some of the radiating elements does not radiate due to some unforeseen reasons, then the entire antenna pattern gets distorted. It degrades the SLL and destroys the pattern null created to suppress the interference from particular directions. In the process of compensation for the element failure the excitations of the working elements are re-optimized to form a new pattern that is close to the original. Several numerical and soft-computing based techniques have been successfully implemented for this compensation problem [6-9], which produces a pattern with minimal loss of quality. As far as our understanding goes, only sidelobe suppression in failed array is discussed in literature [6-9], but the problem of null steering along with sidelobe suppression in failed array is not addressed. In this work we have attempted on both issues of the failed array i.e. SLL and null position which were damaged due to array failure. An evolutionary optimization technique, viz. PSO [10] is used to re-optimize the excitation of the working elements to obtain the a pattern close to the original pattern. A linear Chebyshev array was taken as the candidate antenna and tested for the developed procedure. It can be extended to planar arrays also.

2. Problem Formulation

The far-field pattern of an *N*-element linear array, equally spaced, nonuniform amplitude and progressive phase excitation is given by [1]

$$F(\theta) = \frac{EP(\theta)}{F_{\max}} \sum_{n=1}^{N} w_n e^{j(n-1)kd\cos\theta} \tag{1}$$

where w_n accounts for the nonuniform current excitation of each element. The spacing between the elements is d, θ is the angle from broad side. $EP(\theta)$ is element pattern. $EP(\theta)$=1 for isotropic source. F_{max} is peak value of far filed pattern. Element failure in an antenna array degrade the nulling regions and also cause sharp variations in the field intensity, increasing both sidelobe and ripple level of power pattern. In the present work in addition to the SLL suppression the maintenance of the null position was carried out for the defected array. So the goal is to determine the weights of the working elements of array to maintain the

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null performance and to restore the peak sidelobe power of a damaged array close to the original value in the presence of element failure.

2.1 Sidelobe level suppression

Assuming no radiation from the failed elements, PSO was applied to recover the SLL close to the desired level. It minimizes a cost function, and returns optimum current excitations for the working elements that will lead to the desired radiation pattern with suppressed SLL. Optimizing the pattern of a antenna array with failed elements using PSO was performed by minimizing the following cost function:

$$C = \frac{1}{N_{tot}} \sum_{i=1}^{N_I} \left(\left| F_{PSO}(\theta_i) \right| - Mask(\theta_i) \right)^2 \tag{2}$$

where *Mask* is an upper bound on the array factor enforcing a peak sidelobe power of -30dB in the region $|\theta| \geq 8^0$. The main lobe region is defined as the region $|\theta| \leq 8^0$. In this region the *Mask* is valued as 0 dB. The $F_{PSO}(\theta)$ is computed using the samples θ_i of size N_I which exceed *Mask* and is normalized by the total number of samples N_{tot} used to sample the entire range. Fig.(1) shows both the original Chebyshev array pattern and the mask used in the cost function to restore the pattern.

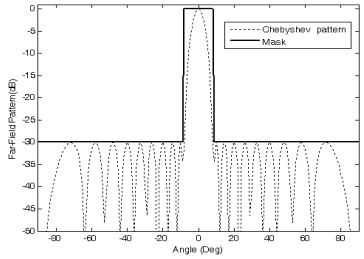

Figure-1 Chebyshev array pattern and the Mask used for corresponding damaged pattern.

2.2 Null steering in failed array

In this part of the work in addition to the SLL suppression the maintenance of the null position was carried out for the defected array. So the goal is to determine the weights of the working elements of array to maintain the null performance of a damaged array. The PSO minimizes a cost function, and returns optimum current excitations for the unfailed elements that will lead to place the null at the same position as before. The cost function that the PSO minimizes is given by:

$$J = \sum_{\theta=-90^0}^{90^0} \left[W(\theta) \left| F_{PSO}(\theta) - F_d(\theta) \right| \right] + C \tag{3}$$

$F_{PSO}(\theta)$ is the pattern obtained by using PSO, $F_d(\theta)$ is the desired pattern, and $W(\theta)$ is the controlling parameter for creating the null. *C* is the parameter as given in eqn. (2) and is used for SLL suppression purpose.

3. Results and Discussion

For the implementation of the developed methodology, a 20-element linear Chebyshev array with λ/2 inter-element spacing was taken as the test antenna. Standard analytical procedure was applied to find the non-uniform excitations of a -30dB sidelobe level (SLL) in the Chebyshev array as shown in Fig. 1. Then the SLL suppression and null steering issues were considered.

At the first instant the element failure in the antenna array was considered with defective elements at 2nd and 3rd position. With this the sidelobe was increased by around 7 dB. To obtain the optimal results the simulation with PSO for 30 particles in 20 dimensions was performed. The performance of PSO for this failure case is demonstrated in Fig.2 for a broadside array. The dotted line plot shows the recovered pattern. This approach was extended to three element failure correction in the antenna array. Fig. 3 shows the

results for the sidelobe suppression in the presence of defective elements present at 2nd, 3rd and 18th position.

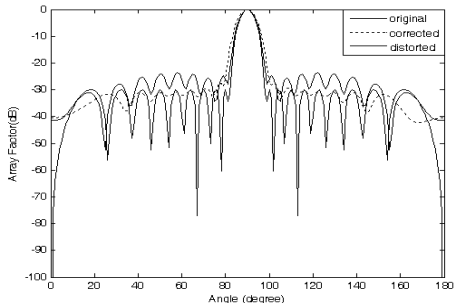

Fig.2. Distorted and Compensated pattern with two failed element positioned at 2 and 3 in 20 element antenna array.

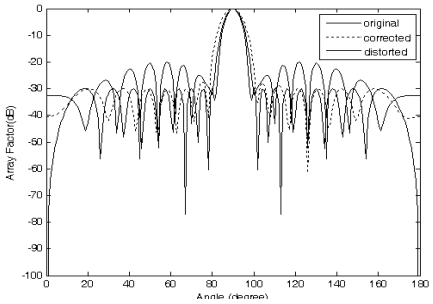

Fig.3 Distorted and Compensated pattern with three failed element positioned at 2,3 and 18 in antenna array.

The null steering was performed for single, multiple and sector nulls in the imposed directions by recalculating the amplitude and phase of each array element by using PSO algorithm. Then some of the array elements were considered as failed elements by equating their excitations to zero. It was observed that the nulling performance was degraded significantly. In order to obtain the desired nulling pattern with failed array that has a good parity with the pattern before failure, the current of the remaining working elements were adjusted by PSO. The proposed method was validated by considering few examples of pattern synthesis with null steering of a linear antenna array with defective elements.

In this case, it was assumed that the single null of the fully functional array was at 20^0 direction. Fig. 4 shows the corresponding radiation pattern created by modifying the excitations of the array elements. At the first instant the element failure in the array was considered with defective elements at 3rd and 18th position. With this the sidelobe was increased by around 10dB and existing null was destroyed. The performance of PSO for this case is demonstrated in Fig.5. As it can be marked clearly from the figure, in addition to the SLL suppression the null was maintained at its previous position i.e. at 20^0. The value of different parameters in the cost function were selected as $F_d(\theta)$= 0, $W(\theta)$ = 100 for $\theta = \theta_i$(direction of interference) and $W(\theta) = 1$, for other directions.

Chebyshev pattern with double nulls imposed at the directions θ_1 =-42^0 and θ_2= 18^0 were achieved by optimizing the current excitations of the array elements. The corresponding pattern is shown in Fig.6. The antenna array with faults at same positions (i.e. 3rd and 18th) were considered. The degraded pattern (dotted line)due to element failure and the recovered optimized pattern (solid line) with two nulls at -42^0 and 18^0 are shown in Fig. 7.

The broadband interference suppression can be achieved by the application of the sector nulling methods. In the present work the pattern with broad nulls located at 30^0 with $\Delta\theta_i = 5^0$ was obtained by perturbing the amplitude and phase of the elements of antenna array and is shown in Fig. 8. It was observed that the performance of the broad null was degraded when the array elements positioned at 2, 3, and 18 became non-radiating. The same procedure can be extended for recovery of the sector null. Fig.9 shows the damaged pattern (dotted line) and the corrected pattern (solid line) with the sectored null at 30^0.

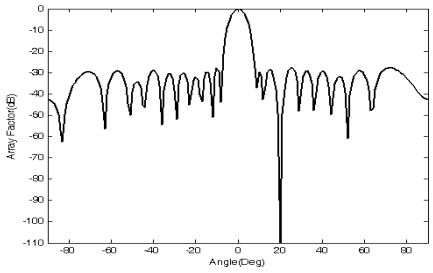

Fig.4 Radiation pattern of 20 element linear broadside array with null at 20^0 and SLL of -30dB.

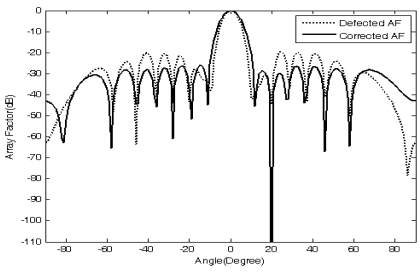

Fig.5 PSO performance for failed array with failure at 3rd and 18th element and single null.

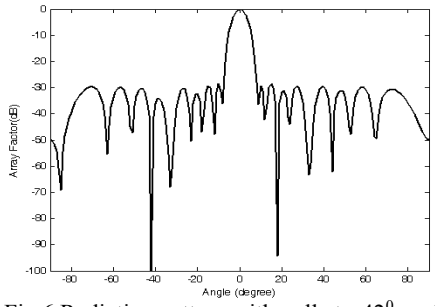

Fig.6 Radiation pattern with null at -42^0 and 18^0 and SLL at -30dB.

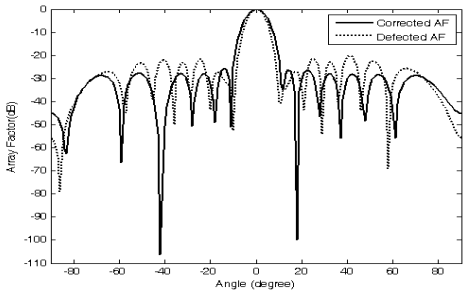

Fig.7 PSO performance for failed antenna array with failures at 3^{rd} and 18^{th} element and double null.

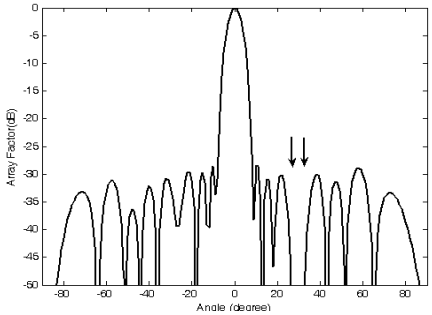

Fig.8 Radiation pattern of 20-element linear array with broad null at 30^0.

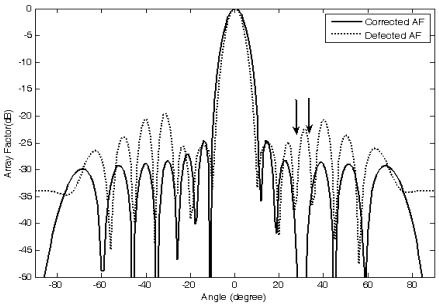

Fig. 9. PSO performance for recovery of sectored null in failed array.

4. Conclusion

The problem of maintaining null positions and SLL suppression in failed antenna array is approached as an optimization problem and solved successfully using PSO. The role of the PSO was to find the optimized set of the amplitude and phase excitations of the working elements in array to get the desired pattern. In this process of compensation the SLL was reduced and null was restored at its original position. The proposed technique is simple and easy to implement and can be extended for arrays with complex geometry by modifying the associated evaluation function. The developed methodology can be helpful in increasing the life span of the arrays, particularly for the arrays without direct human access. At the same time it can save the hardware replacement cost also.

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