Null Steering in Failed Antenna Array

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Abstract—Creation of nulls in specified directions is desirable in order to reduce the effect of interfering signals. But in large antenna arrays there possibility of getting a fault from some of the radiating elements can not be denied. In such a situation, the pattern of the array get distorted mostly with an increasing sidelobe level and removable of the null from its desired position. In this paper a method using particle swarm optimization (PSO) is developed to maintain the null position of the failed antenna array.

Keywords—Antenna array; SLL; Null Steering; PSO

I. INTRODUCTION

In order to reduce the effect of interfering signals, it is desirable to place nulls in specified direction in beamforming problems. 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 [1]. Different analytical and computational methods are available to obtain the optimum values of the amplitude and phase of each array element for getting desired SLL and to obtained a null in prescribed direction [2-3]. The null and minimum SLL in antenna array can be obtained by optimizing the array geometry [4-5]. 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 computational techniques have been successfully implemented to this compensation problem [6-9], which produces a pattern with minimal loss of quality. But the null steering problem in failed arrays was not addressed in the literature.

In this work we have attempted to show the feasibility of using failed antenna array as a normal array and concentrated on the null steering and SLL suppression issues. Instead of analytical techniques an evolutionary optimization technique, viz. PSO is used to re-optimize the excitation of the working elements. A linear Chebyshev array was taken as the candidate antenna and tested for the developed procedure. It can be extended to planar array also.

II. PROBLEM FORMULATION

A. Theory

When the array elements are symmetrically placed and excited around the centre of the linear array having uniform spacing between the elements, the far field array factor of this array with an even number of isotropic elements (2N) can be expressed as [1]

$$AF(\theta) = 2 \sum_{n=1}^{N} a_n \cos\frac{2\pi}{\lambda} d_n \cos \theta + \Phi_n$$  (1)

where $a_n$ and $\Phi_n$ are respectively the amplitude and phase excitation of $n^{th}$ element. $\theta$ is the angle from broad side. $d_n$ is the distance between the position of $n^{th}$ element and the array's centre.

In the null direction, $AF(\theta) = 0$. Element failure in antenna arrays destroys the pattern and the degradation is mostly in the form of increased SLL. In the present work in addition to the SLL suppression the maintenance of the null position was carried out for the defected array. We have assumed the failure as complete, i.e. no radiation from that element. The PSO was applied to recover the SLL and to maintain the null position according to the required specifications. PSO minimizes a cost function, and returns optimum
current excitations for the unfailed elements that will lead to the desired radiation pattern with suppressed SLL and the null at desired position. The reason of choosing PSO over other evolutionary technique is that it is easy to implement and performance is better. The cost function that the PSO minimize is given by:

\[ C = C_1 + C_2 \] (2)

\[ C_1 = k (SLL_o - SLL_d)^2 \] (3)

\[ C_2 = \sum_{\theta = -90^\circ}^{90^\circ} \left[ W(\theta) |AF_o(\theta) - AF_d(\theta)| \right] \] (4)

The first term of the cost function in (2) used for the purpose of SLL suppression. \( SLL_o \) and \( SLL_d \) in (3) are respectively the normalized sidelobe level of actual pattern and the desired pattern. Coefficient \( k \) is the weight, controlling the optimization process. This second term of the cost function in (2) is for interference suppression i.e. to place nulls at specified directions, with the presence of fault elements is expressed in (4), where, \( AF_o(\theta) \) is the pattern obtained by using PSO, \( AF_d(\theta) \) is the desired pattern, and \( W(\theta) \) is the controlling parameter for creating the null.

B. Particle Swarm Optimization (PSO)

PSO is an evolutionary computational technique based on the movement and intelligence of swarms[10]. It is simple to apply, easy to code and high performance computational technique. This algorithm is capable of solving difficult multidimensional optimization problems. It has already been applied successfully for solving many electromagnetic problems[10].

According to PSO terminology every individual swarm is called particle. Initially the particles are placed within a space with the dimensions equal to the number of design parameters used in the optimization. The performance of each particle is measured according to the mathematical function called "cost function". A cost function is a measure of the deviation from the desired value.

All the particles moves in a search space and update their velocity according to the best position already found by themselves i.e. personal best and by their neighbors i.e. global best, and try to find an even better position.

In the present application of PSO, 30 initial particles were taken and they were manipulated according to the following equation:

\[ v_{n+1} = w v_n + c_1 \text{rand}(p_{\text{best},n} - x_n) + c_2 \text{rand}(g_{\text{best},n} - x_n) \] (5)

where \( v_n \) is the velocity of the particle in the \( n^{\text{th}} \) dimension and \( x_n \) is the particle's coordinate in the \( n^{\text{th}} \) dimension. The parameter \( w \) is the inertial weight, that specifies the weight by which the particle's current velocity depend on its previous velocity. \( p_{\text{best}} \) and \( g_{\text{best}} \) are the personal-best and global-best respectively. \( c_1 \) and \( c_2 \) are two scaling factors which determine the relative pull of \( p_{\text{best}} \) and \( g_{\text{best}} \). \( \text{rand}( ) \) is a random function in the range \([0, 1]\).

Once the velocity has been determined it is easy to move the particle to its next location. The velocity is applied for a given time-step \( \Delta t \) and the new coordinate \( x_n \) is computed as

\[ x_{n+1} = x_n + \Delta t \times v \] (6)

During this iterative process, the particles gradually settle down to an optimum solution.

III. RESULT AND DISCUSSION

For the implementation of the developed methodology, a 20-element linear Chebyshev array with \( \lambda/2 \) 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. The null was initially paced at 200 by modifying the excitations of the array elements as shown in Fig. 2.

At the first instant the element failure in the antenna 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. 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.3 for a broadside array. 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 200.

This method of finding the excitations can easily be extended for the patterns with main beam directed at any angle. Fig. 4 shows the pattern of the 20 element linear array with a null at 200, main beam
directed at -30° and the SLL maintained at -30db. The formulation was applied for the failed array with faults at the same positions i.e. 3rd and 18th. The corrected array pattern with the main beam pointing at -30° and maintaining the null at the 20° is shown in Fig.5. The procedure can be extended to other array types as well as for multiple nulls.

![Pattern of 20-element linear Chebyshev array](image1)

**Figure 1.** Pattern of 20-element linear Chebyshev array

![Radiation pattern of 20 element linear broadside array](image2)

**Figure 2.** Radiation pattern of 20 element linear broadside array with null at 20° and SLL of -30dB.

![Radiation pattern for 3rd and 18th element failure with main beam at broadside](image3)

**Figure 3.** Radiation pattern for 3rd and 18th element failure with main beam at broadside. Solid line: the corrected pattern and dotted line: the damaged array pattern.

![Radiation pattern of 20 element linear array with null created at 20° main beam at -30° and SLL at -30dB](image4)

**Figure 4.** Radiation pattern of 20 element linear array with null created at 20° main beam at -30° and SLL at -30dB

![Radiation pattern for 3rd and 18th element failure with main beam at -30°](image5)

**Figure 5.** Radiation pattern for 3rd and 18th element failure with main beam at -30°. Solid line: the corrected pattern and dotted line: the damaged array pattern.

IV. 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 sidelobe level was reduced, null was restored at its original position. It was observed that the computation time of this method depends on number of elements failed and the position of the failed elements. The proposed technique is simple and easy to implement and can be extended for arrays with complex geometry by modifying the associated evaluation function.
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REFERENCES