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FAILURE CORRECTION OF LINEAR ARRAY ANTENNA WITH MULTIPLE NULL PLACEMENT USING CUCKOO SEARCH ALGORITHM

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Abstract
The influence of evolutionary algorithms enhanced its scope of getting its existence in almost every complex optimization problems. In this paper, cuckoo search algorithm, an algorithm based on the brood parasite behavior along with Levy weights has been proposed for the radiation pattern correction of a linear array of isotropic antennas with uniform spacing when failed with more than one antenna element. Even though deterioration produced by the failure of antenna elements results in various undesirable effects, consideration in this paper is given to the correction of side lobe level and null placement at two places. Various articles in the past have already shown that the idea to correct the radiation pattern is to alter the amplitude weights of the remaining unfailed elements, instead of replacing the faulty elements. This approach is made use of modifying the current excitations of unfailed elements using cuckoo search algorithm such that the resulting radiation pattern is similar to the unfailed original pattern in terms of side lobe level and null placement at two places. Examples shown in this paper demonstrate the effectiveness of this algorithm in achieving the desired objectives.

Keywords:
Array Failure Correction, Linear Array, Cuckoo Search Algorithm, Side Lobe Level, Multiple Null Placement

1. INTRODUCTION

Antenna arrays [1] enjoyed its success over individual antenna elements due to their notable characteristics like steering, maximum signal to interference ratio, diversity gain in multipath signal reception, etc. This is made possible by number of factors controlling the array factor of the antenna array, like geometry of the array, amplitude and/or phase excitations of the individual elements. In spite of its superiority over individual elements, antenna arrays suffer a lot from the production of high Side lobe level (SLL), which is referred to as the ratio of the amplitude of main lobe peak to that of the amplitude of the side lobe peak. It is usually expressed in decibels. This undesired increase in level gets aggravated when there is a failure of even at least one element in the array. This condition of failure is assumed as a zero current excitation for the faulty element. The condition of the resulting radiation pattern find itself quiet unusable for many applications. Replacement or renovating the antenna element is the initial idea of restoring the original pattern. But this becomes cumbersome in terms of time and cost especially in applications like satellite and radar etc. This problem also results in disruption of the signal trans-reception used by the particular antenna array.

Researches have been done in the past to overcome the above mentioned problem and the solution that has been suggested is to provide a new set of amplitude and/or phase excitations to the remaining unfailed elements such that the resulting radiation pattern resembles in appearance closely to that of the original pattern. This idea proved as a great boon to the expectation of undisrupted telecommunication services.

Researches on the various array failure correction techniques were found in [2]-[6]. The technique of replacing the signals from the damaged/failed elements in a digital beam forming receiving array was done by Mailloux [2]. Using spatial separation of the incident signals, Steyskal and Mailloux [3] enabled the reconstruction of a missing element's signal and it altered the excitations of only few number (one-third) of total elements in obtaining the success in failure correction. Rodriquez et al. [5] utilized simulating annealing technique for failure correction by generating amplitude and phase excitations (keeping original amplitudes) separately for the remaining unfailed elements. Yeo and Lu [6] proposed genetic algorithm for correction of one, two and three element failures out of 32 elements for restoring the radiation pattern to a prescribed SLL.

Researches did not only comply with failure correction techniques, but also exposed various failure detection techniques, which is a primary requirement before failure correction process to take place. Rodriquez et al. [7] (Genetic algorithm), Patnaik et al. [8] (Artificial Neural Networks) and Balamati Choudhury et al. [9] (Bacteria foraging optimization) used the optimization techniques for fault finding in antenna arrays.

Based on the success of the researches, every now and then new evolutionary algorithms started emerging with variations in the objective function to be optimized as required for variety of applications. Particle swarm optimization has proved its success in synthesis of a linear antenna array with minimum SLL and wide null control [10]. Enhanced particle swarm optimization was used again for the synthesis dealing with wide null control [11]. Utilization of Iterative Fast Fourier transform for null synthesis of scanned antenna array with minimum SLL was also reported [12].

This paper concentrates on applications where antenna arrays are used for the purpose of establishing an expected SLL with a maximum of two null positions. Or in other words, an expected maximum signal to interference ratio in certain angles is corrected along with SLL during the occurrence of the element failures. In this paper, the authors have applied cuckoo search algorithm [13]-[16] for correcting radiation pattern of a linear array of isotropic antenna with more than one defective element.

2. METHODOLOGY

A linear array of M isotropic antennas [1] positioned in Z-axis is used in this paper. The term isotropic refers to the same radiation intensity in all directions by an antenna. It is assumed that the individual elements in the array are equally spaced at a distance d apart as shown in Fig.1. The free space [1] far-field pattern $FFP(\theta)$ in the vertical plane is given by the following equation Eq.(1).

$$FFP(\theta) = \sum_{n=1}^{M} w_n e^{i(n-1)kd\cos\theta} \quad (1)$$

where, n is the element number, λ is the wavelength, w_n is the excitations (current) of the individual antenna elements, i is the imaginary unit, $k = 2\pi/\lambda$ is the wave number, and θ refers to the angle of the far-field point measured from z-axis as shown in Fig.1.

Normalized absolute far-field in dB is written in Eq.(2) as follows,

$$F_n(\theta) = 20\log_{10}\left[\frac{|FFP(\theta)|}{|FFP(\theta)|_{\max}}\right] \quad (2)$$

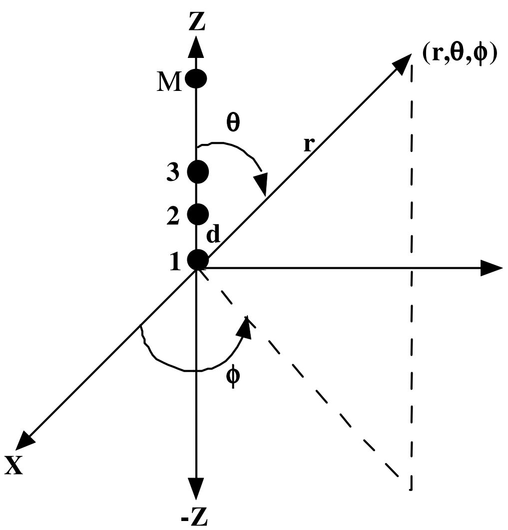

Fig.1. Structure of M-element linear array along the Z-axis

An element failure in the arrays implies that there is no current in it and hence it does not have the power to radiate energy. In this paper, the authors have used the value of current to be zero for a failed element during simulations.

The objective is to obtain a new set of current amplitudes for the remaining unfailed elements using the Cuckoo search algorithm. This algorithm will minimize the following fitness/objective function and restored the expected SLL and two positions as in original pattern.

$$Fitness = \left[wt_1 \times F_1^2 + wt_2 \times F_2^2 + wt_3 \times F_3^2\right] \quad (3)$$

where,

$$F = \begin{cases} SLL_o - SLL_d, & if \rightarrow SLL_o > SLL_d \\ 0, & if \rightarrow SLL_o \le SLL_d \end{cases} \quad (4)$$

$$F_2 = F_3 = \begin{cases} SN_{\max}^{o} - SN_{\max}^{d}, & if \rightarrow SN_{\max}^{o} > SN_{\max}^{d} \\ 0, & if \rightarrow SN_{\max}^{o} \le SN_{\max}^{d} \end{cases} \quad (5)$$

The coefficients wt_1, wt_2 and wt_3 attached to the individual functions in Eq.(3) refers to the weight (importance) given to each term multiplied with those weights.

The value of the weights wt_1 = 14, wt_2 = 1and wt_3 = 1 has been used for generation of original pattern, and wt_1=15, wt_2 = 1and wt_3 = 1 for generation of corrected pattern. SLL_d and SLL_o are desired and obtained values of side lobe level, $SN_{\max}^{o}$ and $SN_{\max}^{d}$ are obtained and desired value of maximum null depth at 140° for F_2 and 160° for F_3 respectively.

3. CUCKOO SEARCH ALGORITHM

Cuckoo Search algorithm has been introduced in 2010 by Yang and Deb. In this section, a review of this algorithm is done before application of the same in solution to the problem taken. This algorithm relies on the brood parasite characteristics of Cuckoo along with the Lévy walk characteristics.

3.1 BREEDING BEHAVIOR OF CUCKOO

Cuckoos are medium (average) sized graceful birds belonging to the family Cuculidae and are popular for the sound they create along with their tough nature in terms of breeding principles. Certain species of Cuckoo place their own eggs in other Cuckoo's nests and allow other Cuckoos to incubate their offspring. These Cuckoos may remove other Cuckoo's eggs to expand their hatching probability of their own eggs [15]. A quite a number of castes involve the helpless children parasitic by putting their eggs in other cuckoos nests. Few class of Cuckoos has a certain level of probability in identifying other Cuckoo's eggs placed in its nests and it ends up in either throwing those eggs out or abandon its own nest and go for a new nest. Female Cuckoos (Tapera caste) has a special feature that it can mimicry in colors and pattern of other hosts Cuckoo's eggs in order to avoid their eggs thrown away by the host Cuckoos [15]. This proves as an advantage to this species of Cuckoo that their eggs will not be discarded by the host Cuckoos resulting in increased re-productivity of their class.

3.2 LÉVY FLIGHTS

The reason for the animals searching for their prey/good completely depends on their current location and transition probability to another location. Mathematical models aid in identifying their new chosen direction. Literature review shows that the flight characteristics of many insects/animals have exhibited the Lévy flights [16] characteristic features. Here, in this Lévy flights, the step-length taken by the insects/animals are based on a heavy tailed probability distribution.

3.3 CUCKOO SEARCH IMPLEMENTATION

Each egg in a nest is entitled to be a solution for the problem undertaken. Even though the algorithm can be extended in which each and every nest can hold multiple eggs representing a set of solutions [13]-[14], here in this paper, it is assumed that each nest has only one egg. The following three rules used by Yang and Deb are adopted here also.

- Each cuckoo lays one egg at a time, and dumps it in other Cuckoo's nest and this nest is chosen in a random fashion
- The best nests with best quality of eggs will get forwarded to the succeeding generations
- The probability with which a host Cuckoo searches for a gringo egg is $P_a \in [0, 1]$. If found, the host bird will abandon its nest or discard the egg.

A pseudo code is shown below which is based on the above summarized three rules.

(i) To start with, the initial population is generated for m host nest. y_k,(k = 1,2,3,….,m).

(ii) A random cuckoo is obtained using Lévy flights and its fitness Fit_k is checked. A random nest is selected for example j

(iii) If the value of fitness is found to be $Fit_k <= Fit_j$, then k is retained as the solution or if the value of fitness is found to be $Fit_k > Fit_j$, then j is treated as the solution instead of k.

(iv) This strategy is succeeded by discarding of predetermined fraction of poor quality nests and using Lévy flights, new nests are constructed at new locations. Then the current best is chosen by ranking the solutions.

The steps (ii)-(iv) above are continued until the maximum number of generation limit is arrived or any external stop specification is reached.

Once the above algorithm is run, the best nest is chosen as the optimum variable and in this case, it refers to the new current amplitudes of linear antenna array elements.

For any Cuckoo y_k, the new solutions are

$$y_k(t+1) = y_k(t) + \alpha \oplus L\acute{e}vy(\lambda), \quad (6)$$

where, α refers to the step size with $\oplus$ representing the entry wise products [14] and

$$L\acute{e}vy\ u = t^{-\lambda},\ (1 < \lambda \leq 3) \quad (7)$$

where, in the above equation, λ is a parameter dealing with fractal dimension and t being the step size. The value of probability P_a used in this paper is 0.25 as used by Yang and Deb.

4. RESULTS

The authors in this paper have considered linear array placed along Z-axis consisting of 30 isotropic antennas with uniform spacing of 0.5λ between individual elements. The patterns (original and corrected) need to be constructed with the following requirements: Side lobe level of -20dB or less and specified maximum null depth of -55 dB or less at 140° and 160°. The free space far field pattern is generated in the principal vertical plane (YZ-plane).

The failed elements are chosen randomly. In this paper, third element (I_3=0), ninth element (I_9=0) and twenty ninth element (I_{29}=0) are chosen to be faulty ones out of 30 elements. The following procedure is adopted for simulations using Matlab.

Case 1: To generate original pattern (without failures) Cuckoo search algorithm is run for 900 iterations. This algorithm minimizes the fitness functions and returns a set of current amplitude values for 30 elements. The total number of particles considered in generating the original pattern is 40.

Case 2: To obtain the damaged pattern, three elements (third element, ninth element and twenty ninth elements) as mentioned above is considered to be faulty. This is done by setting I (3); I (9) & I (29) equal to zero in the excitation of case 1. With this settings, the damaged pattern is generated.

Case 3: To generate the corrected pattern in the presence of defective elements like the third, ninth and the twenty ninth elements, Cuckoo search algorithm is again run for 1100 iterations with the same particle size of 40 as used in generating original pattern. Again, the Cuckoo search algorithm minimizes the fitness function and generates a new set of current amplitudes corresponding to non-defective elements excepting the faulty elements as I(3), I(9) and I(29) are kept zero.

Matlab has been used here for simulation purposes. The computational time is measured with a PC with Intel core2 duo processor of clock frequency 2.93GHz and 4 GB of RAM. Table.1 shows the desired and obtained comparative results among original (case 1), damaged (case 2) and corrected pattern (case 3). Fig.2 shows the normalized current amplitude distribution for original and corrected pattern. Fig.3 and Fig.4 shows normalized original power pattern (far field pattern) and damaged power pattern (far field pattern) in dB with original excitations with Fig.5 showing normalized corrected power pattern (far field pattern) in dB.

Table.1. Desired and Obtained Results

Design Parameters	**Desired Value**	**Obtained Value for Case 1**	**Obtained Value for Case 2**	**Obtained Value for Case 3**
Side Lobe Level in dB	-20	-20.04	-15.70	-19.72
Single Null in dB (θ = 140°)	-55	-55.10	-25.69	-64.55
Single Null in dB (θ = 160°)	-55	-65.98	-25.80	-55.63
Computation time (Seconds)	………	1951.36	…………	2716.63

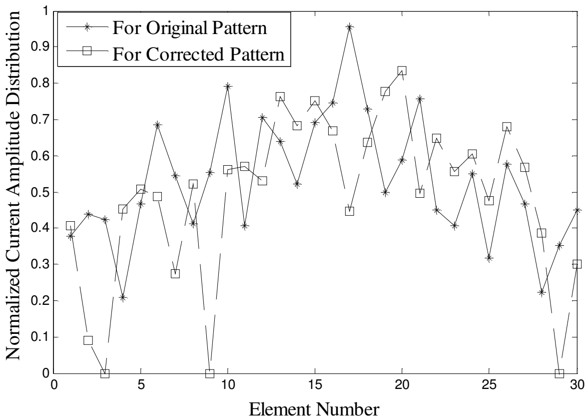

Fig.2. Normalized Current Amplitude Distribution versus Element Number for Case 1 and Case 3 with asymmetric excitations

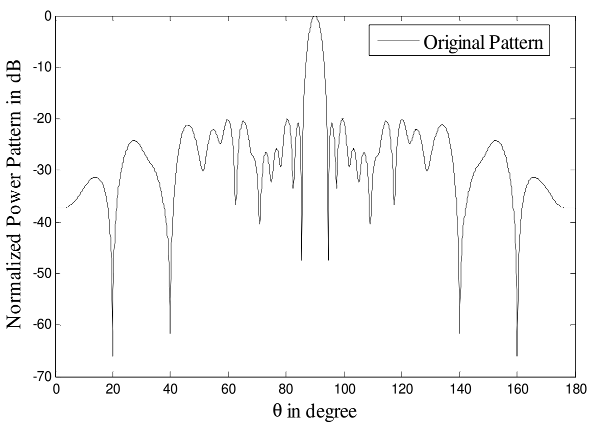

Fig.3. Normalized Original Power Pattern in dB for 30 elements linear array with multiple nulls of prescribed depth of -55dB at θ = 140° and 160°

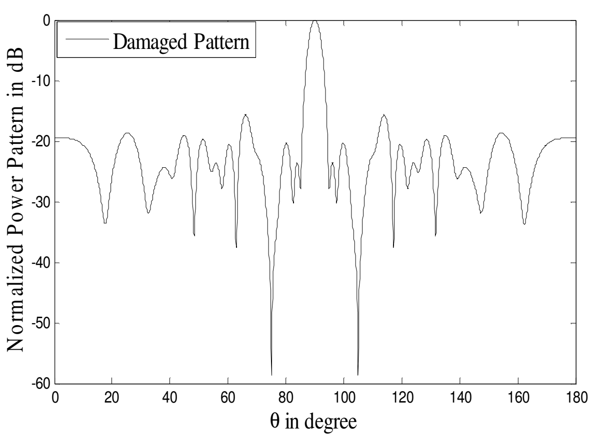

Fig.4. Normalized Damaged Power Pattern in dB for 30 elements linear array considering 3rd, 9th and 29th element to be faulty with Original excitations

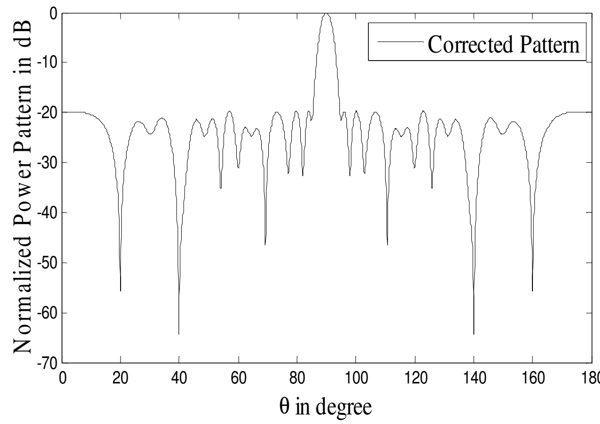

Fig.5. Normalized Corrected Power Pattern in dB for 30 elements linear array considering 3rd, 9th and 29th element to be faulty with multiple nulls of prescribed depth -55dB at θ = 140° and 160°

5. CONCLUSIONS

This paper applied cuckoo search algorithm for failure correction of a linear array of isotropic antennas with uniform inter element spacing in order to obtain expected fixed side lobe level and fixed maximum single null depth at two places. The results obtained using simulations shows that the null depth value was clearly obtained at two different positions as required with a good and a significant improvement in the value of side lobe level is achieved when compared with the damaged pattern. This work can be extended to other geometries of antenna arrays like planar, circular array etc. Moreover, a comprehensive study can be made by variation in number of elements used, spacing between individual antennas, inclusion of mutual coupling etc.

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