Application of Iterative Fast Fourier Transform for Fault Finding in Linear Array Antenna with various Fault Percentage

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***Abstract*— In this paper, the detection of faulty elements in a linear antenna array with different combination of faulty element; is presented. The task of finding faulty element position and its level of fault in antenna arrays has been solved by using Iterative Fast Fourier Transform (IFFT) technique. A Chebyshev antenna array of 30 elements with specific sidelobe level (SLL) is considered as the basic antenna array and the developed formulation is tested on it. Various combinations of failure have been considered in this work and successfully detected using the developed methodology. All the Simulated results has been explained, tabulated and presented with different figures successfully.**

Keywords-Antenna Array; Fault Finding; Iterative Fast Fourier transform

I. INTRODUCTION

In the modern communication world, antenna arrays are a common term now because of the flexibility and control that they allow over the radiation pattern. The active antenna arrays are generally used in many different applications such as wireless radio system, mobile, radar and satellite communication [1]. In some applications the antenna array consists of very large number of radiating antenna elements or sub-arrays [2]. Because of the presence of large number of elements, there is always a possibility of failure of one or more radical elements in a large array. Fault detection is a practical issue which has applications in radar, satellite, mobile and wireless communication [3]. Due to element failure, the radiation pattern disturb in terms of SLLs, damage of nulls and increase of bandwidth. The failure of elements in the array destroy the symmetry and generate the unacceptable pattern distortion and mostly in the form of increased SLLs. The replacement of the defective antenna element of the array is not possible in every situation [4]. But in case of active antennas, without replacing the defective antenna element the radiation pattern can be regenerated with minimum loss of quality by controlling the excitations (inputs) of the unfailed antenna elements of the array [5]. That process not only controls the replacement cost of failed elements but also ensures that, when simple repair and recalibration is not within the reach, the degradation of an error compensated array will be slow and graceful. Several compensation techniques have been reported in different literatures. B.K.Yeo *et al.* have been presented a technique of Array failure correction with a genetic algorithm [6]. R.J. Mailloux find an array failure correction method with a digitally beam formed array in [7]. H. Steyskal *et al.* have been generalized a technique to find array failure correction method [8]. In order to apply given compensation techniques it is very necessary to know the number and position of the failed antenna element in the array.

The presented algorithm in this paper is used successfully for the detection of complete, as well as, for partial faulty elements position. The strategy starts with the Iterative Fast Fourier Transform tracing the amplitude excitations of the defected array. These traced excitations are then compared with the excitations of the original array to detect the faulty antenna element position and its level of fault. Simulation results are evaluated for 30 elements Chebyshev array of specific SLL.

Here, in second part of the paper a brief theory of the antenna array has been given. In the very next part the formulation of the IFFT method has been obtained. In the fourth part, there are simulated results with the generated patterns have been obtained successfully. In the fifth and the last part of the paper, conclusion has been drawn.

II. THEORETICAL FORMULATION

Let us consider a linear array of N number of isotropic antennas [1] that are assumed uncoupled and equally spaced a distance d apart along the Y-axis. That arrangement is shown in Fig.1. The free space [1] far-field pattern $F(u)$ in the principal vertical plane (YZ-plane) is given by (1):

$$F(u) = \sum_{n=1}^{N} A_n e^{i(n-1)kdu} \tag{1}$$

Where n is the element number, λ is the wavelength, A_n is the excitation current amplitudes of the elements, i is the imaginary unit, $k=2\pi/\lambda$ is the wave number, d is the interelement spacing, and $u=\sin\theta$, θ being the polar angle of far-field measured from broadside (-90° to +90°).

Normalized absolute far-field in dB can be expressed as follows:

$$F_n(u) = 20\log_{10}\left[\frac{|F(u)|}{|F(u)|_{\max}}\right] \qquad (2)$$

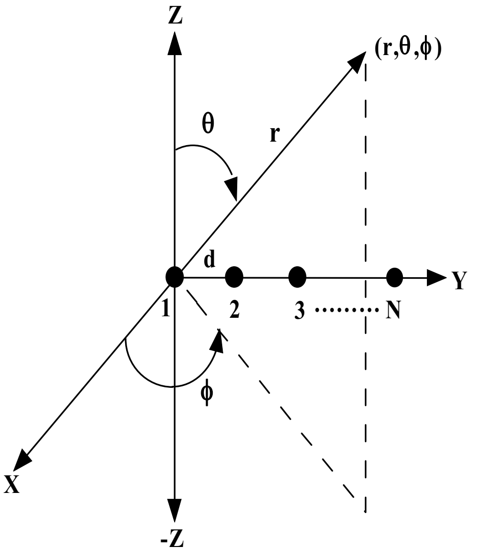

Fig.1. Geometry of an N-element linear array along the Y- axis

III. FORMULATION OF FFT METHOD

Array factor (*AF*) in the vertical plane is given by

$$AF(u) = \sum_{n=1}^{N} A_n e^{i(n-1)kdu}$$

$$Let\ \ p = 1 + \frac{N}{2\pi}kdu$$

$$then\ \ AF(p) = \sum_{n=1}^{N} A_n e^{i(2\pi/N)(n-1)(p-1)} \qquad (3)$$

Through this mapping procedure, the sampling in u domain is transformed into p domain. Equation (3) has the same form with the standard definition of one-dimensional inverse fast Fourier transform (IFFT). It indicates that the array pattern can be directly achieved through an IFFT operation on the excitations A_n.

It can be compared with the conventional element-by-element superposition method. A common advantage of this new approach is that the overall computational complexity is determined by the sampling density rather than the actual array size itself.

First we initiate a chebyshev array with 30 array elements and find the array pattern and their excitations. Then due some faulty elements of the array elements, we got the damaged pattern. After finding the damaged pattern we will obtain elements excitation of damaged pattern by IFFT method. And then we compare the result of the excitation of damaged patterns with the original array pattern.

IV. SIMULATION RESULTS

In this paper, for fault finding the test antenna is taken as 30 Classical Dolph-Chebyshev linear array antennas with equal spacing of 0.5λ between any two consecutive elements. The linear antenna array has been design for a -30 dB constant SLL. In this program we have used 4096-point IFFT with zero padding of interpolation; if excitation current has less than 4096 points.

The original Chebyshev normalized power pattern and normalized weight distribution for 30 elements is shown in Fig.2 and Fig.3 respectively. The Chebyshev weights obtained for 30 elements linear array by analytical method are given in Table 1. In this paper, various combinations of partial as well as complete fault are tested. The obtained weight distributions of the defected array are compared with the original Chebyshev weights distribution to check the complete as well as partial faults by using IFFT.

Initially, we are considering that 4th, 8th, 27th elements are completely failed. Fig.4 and Fig.5 shows the damage normalized power pattern and the weight distribution of the damage pattern respectively. From Fig. 4 it is clear that after failure its pattern become disturb completely and from the damage pattern it will be very difficult to detect the faulty element position. Now we run the program to locate the faulty element position as well as the grade of failure. The weights obtained by IFFT, which shows the location of defective elements are given in Table 1. From Table 1, we can clearly observe the position of faulty element, as well as, the grade of failure of damage elements.

In the next case, we have been tested for the different types of fault combinations. We assumed that the element at the 14th position is completely failed and the 6th and 23th position elements are 50% failed. Fig.6 and Fig.7 shows the damage normalized power pattern and the weight distribution of the damage pattern respectively. The excitations obtained for damaged pattern by IFFT method; which shows the location of defective elements; are given in Table 1. Again from Tabel.1, we can clearly observe the position of faulty element, as well as, the grade of failure of damage elements.

In the third case, we assumed that the fault located at 9th position is completely failed and the elements at the position of 28th and 16th are half and quarterly failed respectively. The damage normalized power pattern and weight distribution of the damage pattern are shown in Fig. 8 and Fig. 9 respectively. The element weights of damaged pattern obtained by IFFT; which shows the location of defective elements; are given in Table 1. From Table 1, we can clearly observe the position of faulty elements, as well as, the grade of failure of damage elements.

Table 1: Obtained and desired results

El. No .	Chebyshev Weights	4^{th}, 8th and 27^{th} (100%) Fault	14^{th} (100%), 6^{th} and 23^{th} (50%) Fault	9^{th} (100%), 28th (50%) and 16^{th} (25%) Fault
1	0.4234	0.4234	0.4228	0.4223
2	0.2477	0.2474	0.2470	0.2470
3	0.3125	0.3128	0.3122	0.3117
4	0.3827	**0.0002**	0.3816	0.3816
5	0.4562	0.4560	0.4559	0.4549
6	0.5321	0.5316	**0.2652**	0.5308
7	0.6079	0.6086	0.6068	0.6059
8	0.6824	**0.0000**	0.6809	0.6817
9	0.7529	0.7512	0.7518	**0.0000**
10	0.8180	0.8185	0.8159	0.8138
11	0.8752	0.8743	0.8744	0.8742
12	0.9236	0.9238	0.9206	0.9199
13	0.9609	0.9601	0.9620	0.9597
14	0.9869	0.9869	**0.0001**	0.9825
15	0.9996	0.9989	0.9944	1.0000
16	1.0000	1.0000	1.0000	**0.2490**
17	0.9867	0.9859	0.9835	0.9816
18	0.9614	0.9615	0.9608	0.9600
19	0.9236	0.9228	0.9208	0.9205
20	0.8759	0.8760	0.8755	0.8740
21	0.8181	0.8173	0.8152	0.8156
22	0.7537	0.7540	0.7545	0.7518
23	0.6825	0.6816	**0.3402**	0.6806
24	0.6089	0.6096	0.6063	0.6073
25	0.5321	0.5306	0.5318	0.5308
26	0.4573	0.4597	0.4562	0.4558
27	0.3824	**0.0004**	0.3819	0.3822
28	0.3141	0.3116	0.3134	**0.1582**
29	0.2461	0.2471	0.2457	0.2443
30	0.4246	0.4236	0.4237	0.4240

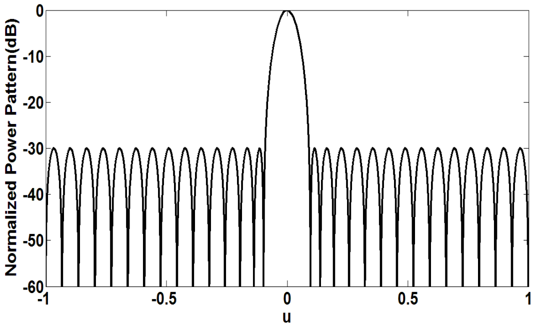

Fig. 2: The Original Chebyshev normalized power pattern for 30 elements

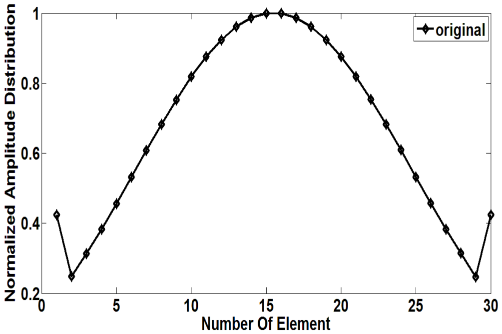

Fig. 3: The Original Chebyshev normalized weight distribution for 30 elements

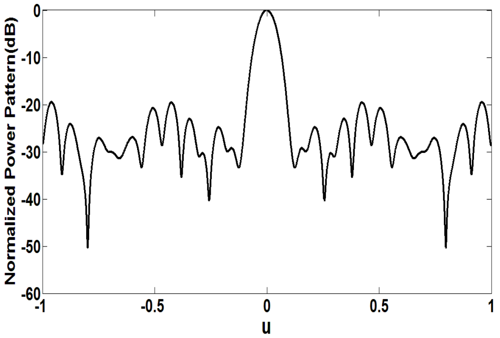

Fig. 4: The damage normalized power pattern when element numbers 4,8,27 are fully fault

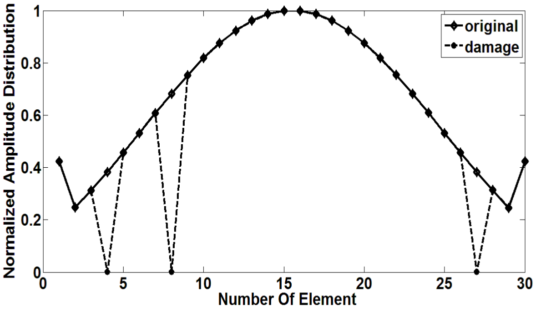

Fig. 5: The damage normalized weight distribution when element numbers 4,8,27 are fully fault

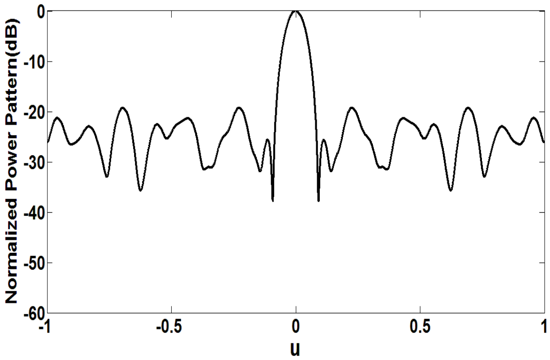

Fig. 6: The damage normalized power pattern when element 14^{th} (100%), 6th and 23^{th} (50%) fault

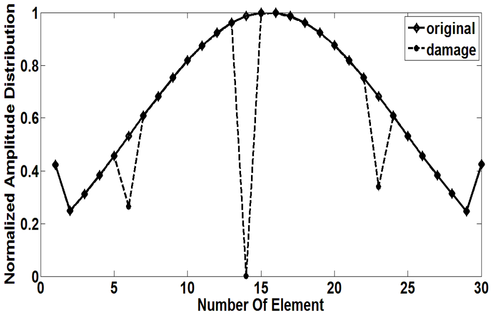

Fig. 7: The damage normalized weight distribution when element 14th (100%), 6th and 23th (50%) fault

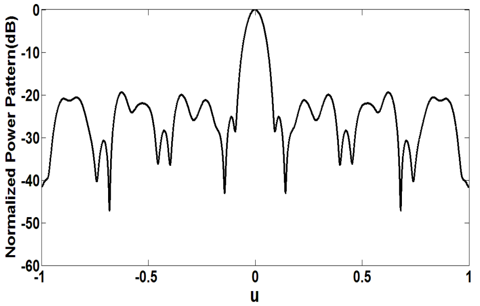

Fig. 8: The damage normalized power pattern when element 9th (100%), 16th (25%) and 28th (50%) fault

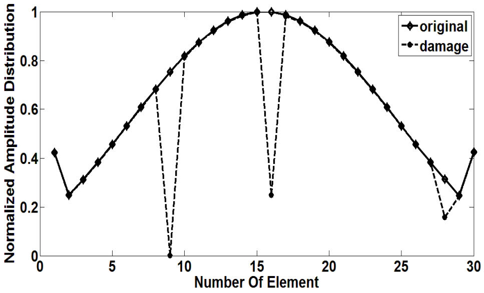

Fig. 9: The damage normalized weight distribution when element 9th (100%), 16th (25%) and 28th (50%) fault

V. CONCLUSION

In this paper, the application of Iterative Fast Fourier Transform for fault finding in a linear array antenna has been successfully discussed and presented. The obtained results are in good agreement with the mentioned values. There would be a large scope of work by doing extensive study on the parameter dependency i.e., number of elements, element spacing and considering mutual coupling effects on the radiation pattern. Although in this work, the results developed for a linear array only but the applicability of Iterative Fast Fourier Technique to different array structures like circular, planar or any non-linear array also could be the next focused area.

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