Finding Defective Elements in Antenna Array Using Fast Fourier Transform

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***Abstract*—A method based on Fast Fourier Transform for detecting the position and the level of fault in antenna arrays, from the degraded far field pattern samples is proposed. The paper considers Chebyshev array of specified side lobe level as a desired antenna pattern and authors develop strategy to test on it. The paper also deals with several different combinations of failures and successfully detects using the proposed technique, which takes lesser computational time than other optimization algorithms. In this paper, the method is developed and applied to a linear array of isotropic antennas; however, the principle can easily be extended to other type of arrays.**

***Index Terms*—antenna array, fault detection, fast fourier transform**

I. Introduction

Antenna arrays [1] are used in various applications like mobile communications, radar and satellite communications because of their high gain. In order to achieve high gain for some applications, the antenna array consists of a large number of radiating elements; thus, there is always a chance of failure of one or more of these elements in a large array. The main beam from a defective array is often distorted and its side lobe level is high. This situation is not acceptable in many applications. In many situations it is not always easy to replace the defective element of the array; however, the radiation pattern can be corrected by changing the excitation of the non-defective elements of the array, without replacing the defective elements. This results in generation of low side lobe level pattern as desired that is also in close match with the original radiation pattern. This method saves cost as replacing the defective elements is not required. This is particularly needed when repair and recalibration is beyond reach.

Several array failure correction techniques were reported in the literature [2]-[4]. In order to apply these correction techniques it is necessary to know the number and position of the defective element in the array. Several fault-finding techniques in antenna array were reported in [5]-[8]. Artificial Neural Networks (ANN) concept for finding complete element failure in antenna array was discussed in [5]. Complete as well as partial fault finding methods based on support vector classifier [6], genetic algorithm [7], Bacteria Foraging Optimization [8] were also reported. These optimization algorithms are useful when the size of the array antenna is small; however, for larger arrays having more than 100 elements, these optimization algorithms may not be useful to find the faulty elements, as the computational time will be in hours, which is not suitable for real time applications.

To overcome this difficulty and to minimize computational time, the authors have applied the Fast Fourier Transform (FFT) [9] to find excitations of defected linear array. These excitations obtained from applying FFT on the defected array factor are then compared with the excitations of the desired array to know the faulty element position and the level of fault.

For a linear array has an equal spacing of the elements, an inverse fast Fourier Transform (IFFT) on the excitation current amplitude produces [9] array factor *(AF).* Because of this relationship, by applying direct fast Fourier transform on the array factor we can get the element excitations. Advantage of this technique is very high processing speed i.e. it takes less computation time. This is because of the fact that the main calculations are based on direct and inverse Fast Fourier Transforms.

As compared with the conventional way of calculating the array factor, an obvious advantage of using IFFT for calculation of array factor is that the overall computational complexity is determined by the number of sampling points used rather than the size of actual array. The computational time is same for a 100-element array or a 1000 element array.

II. Problem Formulation

We have considered a linear array of N isotropic antennas [1]. Antenna elements are equally spaced at a distance d apart along the Z-axis as shown in Fig. 1. The free space [1] far-field broadside pattern $FF(u)$ or array factor (AF) in the principal vertical plane is given by eq. (1):

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

where n is the element number, A_n is the excitation current amplitudes of the elements, i is the imaginary unit, k (=2π/λ) is the wave number, N is total number of elements, d is the inter-element spacing, $u = \cos\theta$, θ being the polar angle of far-field measured from z-axis (0^o to 180^o), and λ is the wavelength.

Normalized absolute power pattern in dB can be expressed as follows:

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

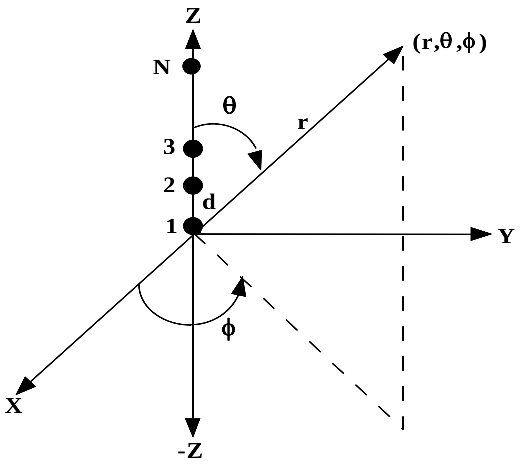

Figure 1. Geometry of an N-element linear array of isotropic antennas along the Z-axis

Element failure in an antenna array [8] causes both side lobe and ripple level of power pattern to increase. In order to find the position of the defective element in the array, it is necessary to measure the degraded pattern of array having one or more faulty element(s). The *AF* of the defected array was determined using eq. (1) by making amplitude excitation equal to zero to represent a completely defective element and half of the original excitation to represent a partially defective element. FFT is then applied on the array factor of the defected array to get excitation current amplitudes directly. This gives the amplitude excitations of the defected array, which were then compared, with the excitations of the original array to find the location and the level of the fault.

III. Formulation of FFT Method

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

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

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

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

$$AF = IFFT(A_n, \text{ no of field point})$$

$$A_n = FFT(AF)$$

By this mapping procedure [9], the sampling in u domain is transformed into h domain. Equation (3) is very similar to that of the standard definition of one-dimensional IFFT and FFT.

IV. Results

In this work, we consider a 20-element linear broadside Chebyshev array with λ/2 inter-element spacing and –25 dB side lobe level as the desired antenna pattern. Standard analytical procedure [1] was applied to find the non-uniform amplitude excitations of the above Chebyshev array. Number of sample points used in FFT was 4096. Fig. 2 shows the array factor plot of the desired chebyshev array and Table 1 shows the normalized amplitude excitations of the array. To validate the proposed fault finding technique, the following three different cases were considered.

A. Case I—Finding of Complete Fault

In this case the second, fifth and eleventh element of the array was considered as complete in fault and the FFT technique was used to locate its position from the array factor of the defected array. This defected AF was obtained by making the excitation of the second, fifth and eleventh element of the original array equal to zero in the eqn.(1) and FFT was used on this array factor to find the excitations of the defected array. To check the effectiveness of the proposed FFT technique, these excitations are compared with the excitations obtained from the original Chebyshev array with excitation of the defected elements equal to zero as shown in Table 1. The amplitude distribution of the defected array obtained using FFT is compared with the distribution of the original array in Table I, which shows a deviation at element number 2,5,7, showing the presence of fault in that element. The amount of difference gives an idea of the level of fault.

B. Case II—Finding of Partial Fault

In this case, making the excitation of the fourth and tenth element equal to half of the original excitation created a partial fault. Then the same method as discussed in case-I was used to detect the position and level of fault in this case also. This was explained in Table I.

C. Case III—Finding of Combination of Partial and Complete Fault

In this case, we tried to locate two different types of faults, partial as well as complete fault. *AF* was formed by making sixth element partially fault and sixteenth element completely fault. Table I shows the details of procedure involved in this case.

The computation time in all cases was measured with a laptop with Intel core2 processor of clock frequency 1.83 GHz and 4GB of RAM.

TABLE I. NORMALIZED AMPLITUDE EXCITATIONS OBTAINED FROM FFT FOR DIFFERENT FAULT CONDITION

. Element number	Original Chebyshev array	Case I Second, fifth and eleventh element complete fault	Case II Fourth and tenth element partial fault	Case III Sixth element partially fault and sixteenth element complete fault
1	0.5665	0.5648	0.5674	0.5666
2	0.3714	**0.0005**	0.3717	0.3710
3	0.4739	0.4718	0.4747	0.4739
4	0.5790	0.5787	**0.2897**	0.5785
5	0.6820	**0.0008**	0.6827	0.6824
6	0.7779	0.7758	0.7787	**0.3885**
7	0.8616	0.8589	0.8628	0.8610
8	0.9288	0.9272	0.9296	0.9286
9	0.9758	0.9721	0.9779	0.9756
10	1.0000	1.0000	**0.5007**	0.9996
11	1.0000	**0.0003**	1.0000	1.0000
12	0.9758	0.9712	0.9780	0.9754
13	0.9288	0.9277	0.9296	0.9293
14	0.8616	0.8592	0.8636	0.8608
15	0.7779	0.7766	0.7786	0.7801
16	0.6820	0.6806	0.6839	**0.0007**
17	0.5790	0.5778	0.5794	0.5761
18	0.4739	0.4736	0.4759	0.4763
19	0.3714	0.3696	0.3705	0.3692
20	0.5665	0.5660	0.5686	0.5682
Computation Time (seconds)	------	0.049553	0.063325	0.052295

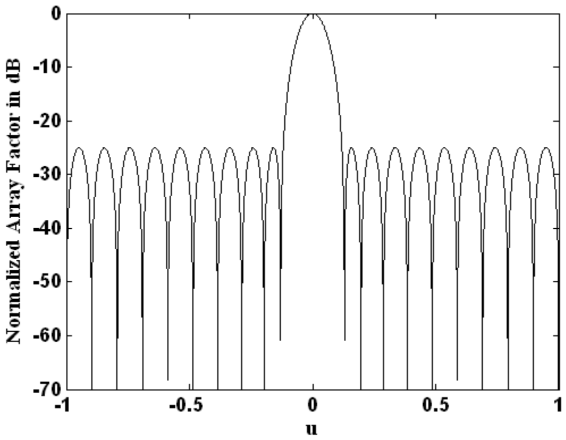

Figure 2. Normalized pattern for 20-element chebyshev array with SLL of -25dB

V. CONCLUSION

The method of fault finding in antenna arrays was demonstrated using FFT technique. FFT was used to find the amplitude excitations from the pattern of the defected array, which is usually done by modifying amplitude excitation of appropriate element in the original array. By comparing these excitations with the excitations of the original array, it has been possible to find the location and level of fault in the defected array. This paper considers partial as well as complete fault scenario and locates them successfully. In all these cases, the computational time is just a fraction of a second, which establishes its effectiveness in real time applications.

Although in this work the authors have considered a linear Chebyshev array as the desired antenna, the same technique is applicable to other type of arrays.

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