Array Failure Correction With Placement of Wide Nulls In The Radiation Pattern of A Linear Array Antenna Using Iterative Fast Fourier Transform

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***Abstract*— The iterative Fast Fourier technique to array failure correction with placement of single wide nulls and dual wide nulls while keeping the side lobe level to its minimum value; are presented in this paper. The paper describes the iterative Fourier technique for the synthesis of low-side lobe patterns for linear arrays with uniform element spacing. The method uses the property that for a linear array with uniform element spacing, an inverse Fourier transform relationship exists between the array factor and the element excitations. This property is used in an iterative way to derive the array element excitations from the prescribed array factor. The effectiveness of this method for realizing lower values of side lobe levels and placing the single wide nulls and dual wide nulls at different FFT points will be demonstrated for linear arrays equipped with 34 elements. This demonstration of effectiveness also involves the recovery of the original low-side lobe levels as close as possible, in case of element failures.**

Keywords-Antenna Array; Fast Fourier transform; Array Failure Correction; Low Sidelobe Level; Wide Nulls

I. INTRODUCTION

Now a day, antenna array is one of the most important components to improve the capacity and spectral efficiency in most widely used applications in field of communication system like satellite, sonar, radar and mobile communication system for signal acquisition purpose. According to type of citation of elements in arrays, Antenna arrays may be linear, two-dimensional, circular and spherical. Generally an antenna array comprises a large number of radiating elements in it. As a result of large number elements, the increment in the probability of failure of one or more elements in the antenna array system occurs. As one or more element fails, the problem of asymmetry in the antenna array arises. These asymmetries cause sharp variation in field intensity across the array and side lobe levels are increased due to distorted pattern [1]. As Communication should not stop even some of the antenna elements failure so to recover from such situations different researches have been working continuously on failure of antenna array elements. At sudden we cannot replace the whole system, which means that instead of finding the alternating paths we have to make the current path dynamic. Here, one of the most eligible possibility to restore the radiation pattern using various techniques as fast fourier transform (FFT) [2, 3], genetic algorithms (GA) [4], particle swarm optimization (PSO) [5], firefly algorithm (FA) [1], with minimal loss of quality without replacing the defective element.

Often, antenna arrays are used to have high directivity so that most of the energy should be transmitted through the main beam with taking care of lowest side band radiations and power losses. So in wireless communication the generation of nulls in the array pattern is important. Here, the nulls can be narrow or wide. To obtain this, one should have an equally spaced array with a specific element amplitude distribution. But, the synthesis problem is complex and difficult to solve with analytical methods. Therefore, global tools of optimization such as genetic algorithms (GA) [6], particle swarm optimization (PSO) [7, 8], and simulated annealing (SA) [9] have been used in array synthesis for different requirements.

The main purpose of this paper is to use a new algorithm based iterative Fourier technique to synthesis for array failure correction by placing of single wide nulls and dual wide nulls [10] in various FFT points and to obtain low side lobe levels of specified value for both of the examples.

There are various methods available for synthesis of array failure correction with placing of wide nulls such as variation of complex excitations i.e. variation of both amplitude and phase [11], variation of only phase [12], variation of element spacing [13] and variation of only amplitude [14]. Generally, antenna elements are usually spaced half wavelength apart to get reduced grating lobes in the radiation pattern of linear arrays. The side lobe level can be reduced to any desired level by tapering the amplitude excitation of the elements. The main task in tapering process is to calculate a suitable weighting vector, which can produce the narrow beam with minimum side lobe level. One major disadvantage of amplitude tapering is increase in beamwidth. It shows that to gain lower amount of side lobe we must accept

978-1-4799-6023-1/15 $31.00 © 2015 IEEE
DOI 10.1109/CICT.2015.33

the increase in beamwidth. Various numbers of analytical and numerical techniques have been developed to provide the trade-off between side lobe level and beamwidth [15].

II. THEORETICAL FORMULATION

Let us take a linear array of N isotropic antennas [16] that are equally spaced a distance d apart along the Y-axis. This is shown in Fig.1. The coupling effect of elements has not been considered here. The free space [16] 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 A_n is the excitation current amplitudes of the elements and n is the element number. λ is the wavelength, i is the imaginary unit, $k=2\pi/\lambda$ is the wave number, d is the inter-element spacing, and $u=\sin\theta$, where θ being the polar angle of far-field measured from broadside (-90^o to $+90^o$).

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

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

III. FORMULATION OF FFT METHOD

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

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

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

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

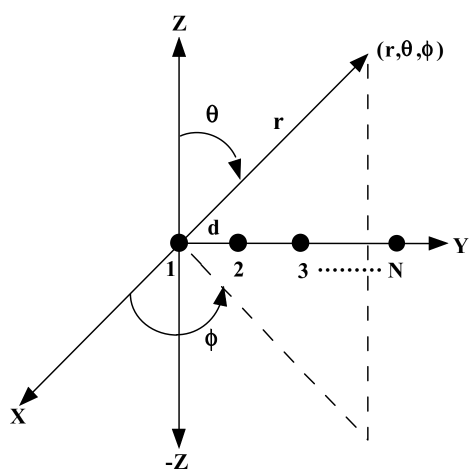

Fig.1. Geometry of an N-element linear array along the Y- axis

After considering 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) which indicates that the array pattern can be directly obtained from an IFFT operation on the excitations A_n.

An obvious advantage of this new approach as compared with the conventional element-by-element superposition method is that the overall computational complexity is determined by the sampling density rather than the actual array size itself.

There are various steps involved in implementation for the synthesis of array failure correction for linear arrays with placing of wide nulls for low side lobe levels of specified value using amplitude-only element weighting proceeds as follows:

Step1: Start the synthesis using a uniform random excitation A_n between 0 and 1 for N elements.

Step2: Compute AF from A_n using a *K-point* inverse FFT (while $K>N$) *and* adapt AF to the prescribed side lobe and wide nulls constraints.

Step3: Compute A_n for the adapted AF using a *K-point* direct FFT.

Step4: Truncate A_n *from* K samples to N samples by making zero all samples outside the array.

Step5: Make the phase of the N samples of A_n equal to the phase of the initial excitation at Step1.

Step6: Enforce the optional defective-element constraint. Take element failures into account by setting their excitation values to zero.

Step7: Repeat Steps 2-6 until the prescribed side lobe and wide nulls requirements for AF are satisfied, or the allowed number of iterations is reached.

IV. SIMULATION RESULTS

In this paper, a linear array structure of 34 isotropic antennas with equal spacing of 0.5λ between any two consecutive elements has been considered. Minimization of side lobe level is done using non-uniform excitation amplitudes of the elements. The program that we have used for the synthesis of linear array antenna is coded in MATLAB. In this program we have used 4096-point IFFT padded with zeros if excitation current has less than 4096 points. Program is run for 3000 iterations for both single and dual wide null cases. Figure 2 to figure 7 shows the normalized power pattern of original, damaged and corrected pattern of single and dual wide nulls respectively. Any number of elements can be failed in the antenna array. In our example we have taken the element number 2, 6, 29, 32 are failures in antenna array.

In case of single wide null specified SLL is -30 dB and the specified depth of wide null is -70 dB at 3400 to 3600 FFT points. For original pattern achieved SLL is -30.0416 dB and null depth is -67.8010 dB but in case of damaged pattern achieved SLL is only -23.7155 dB. For corrected pattern achieved SLL is -30.0502 dB and null depth is -63.4133 dB which is close to the original pattern values. All these results have been shown in table I.

In case of dual wide nulls specified SLL is -30 dB and the specified depth of wide nulls is -70 dB at 3000 to 3200 and 3600 to 3800 FFT points. For original pattern achieved SLL is -30.0229 dB and the depth of first null is -61.6705 dB and second null is -64.3712 dB but in case of damaged pattern achieved SLL is only -23.0052 dB. For corrected pattern achieved SLL is -30.0295 dB and the depth of first null is -66.1771 dB and second null is -65.7611 which is close to the original pattern values. All these results have been shown in table II.

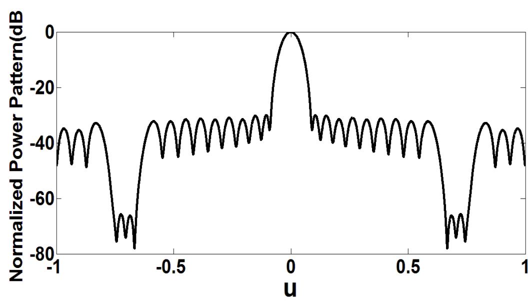

Fig. 2: Normalized power pattern for 34 elements linear array with SLL= -30 dB and single wide nulls of specified depth is –70dB from 3400 to 3600 FFT point

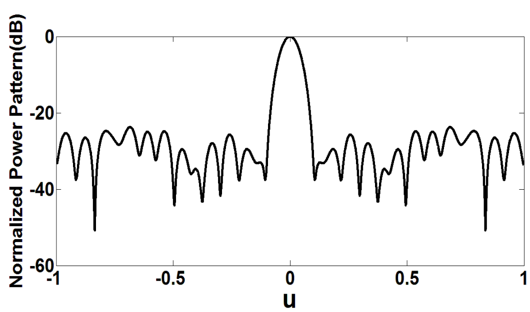

Fig. 3: Normalized power pattern for 34 elements linear array with SLL= -30 dB and single wide null of specified depth is –70dB from 3400 to 3600 FFT point when element 2, 6, 29, 32 are failure

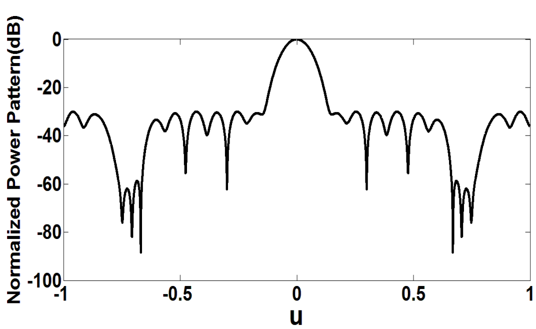

Fig. 4: Corrected Normalized power pattern for 34 elements linear array with SLL= -30 dB and single wide null of specified depth –70dB from 3400 to 3600 FFT point when element 2, 6, 29, 32 are failure.

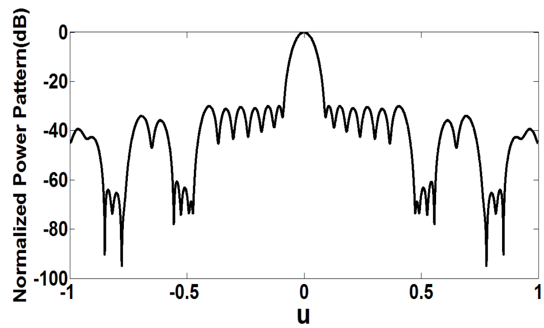

Fig. 5: Normalized power pattern for 34 elements linear array with SLL= -30 dB and dual wide nulls of specified depths is –70 dB from 3000 to 3200 and 3600 to 3800 FFT point

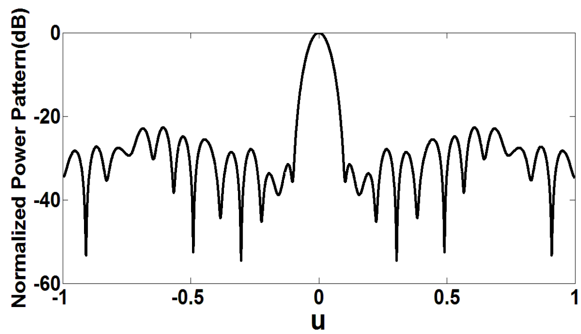

Fig. 6: Normalized power pattern for 34 elements linear array with SLL= -30 dB and dual wide nulls of specified depths is –70dB from 3000 to 3200 and 3600 to 3800 FFT point when element 2, 6, 29, 32 are failure

Table I
Desired and obtained results for single wide nulls

	Design parameter	**Desired level (dB)**	**Obtained level (dB)**
Original	Wide null in dB (3400 to 3600 FFT point)	-70	-67.8010
	Side lobe level in dB	-30	-30.0416
Defected	Wide null in dB (3400 to 3600 FFT point)	-70	–
	Side lobe level in dB	-30	-23.7155
Corrected	Wide null in dB (3400 to 3600 FFT point)	-70	-63.4133
	Side lobe level in dB	-30	-30.0502

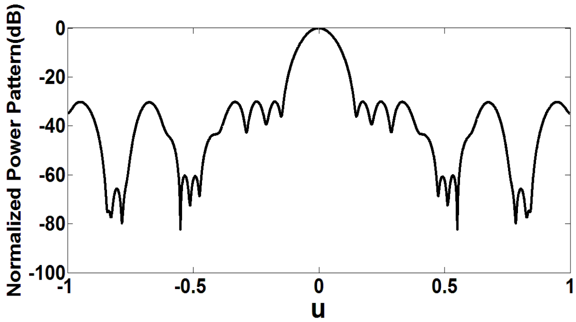

Fig. 7: Corrected Normalized power pattern for 34 elements linear array with SLL=-30 dB and dual wide nulls of specified depths is –70dB from 3000 to 3200 and 3600 to 3800 FFT point when element 2, 6, 29, 32 are

Table II
Desired and obtained results for dual wide nulls

	Design parameter	Desired level (dB)	Obtained level (dB)
Original	First Wide null in dB (3000 to 3200 FFT point)	-70	-61.6705
	Second Wide null in dB (3600 to 3800 FFT point)	-70	-64.3712
	Side lobe level in dB	-30	-30.0229
Defected	First Wide null in dB (3000 to 3200 FFT point)	-70	–
	Second Wide null in dB (3600 to 3800 FFT point)	-70	–
	Side lobe level in dB	-30	-23.0052
Corrected	First Wide null in dB (3000 to 3200 FFT point)	-70	-66.1771
	Second Wide null in dB (3600 to 3800 FFT point)	-70	-65.7611
	Side lobe level in dB	-30	-30.0295

V. CONCLUSION

The examples presented in this paper have demonstrated that the iterative Fourier technique is ideally suited for the synthesis of array failure correction with single wide nulls and dual wide nulls. During this process, specified depth and the SLL to their lowest values for antenna arrays with periodic element spacing should maintain as low as possible. Simplicity and highly robustness is major advantage of this technique. It is very easy to implement in software, requiring only a few lines of code when programmed in *MATLAB*. This technique is having very high computational speed because of the fact that the core calculations used in this technique are based on direct and inverse fast Fourier transforms (FFT).

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