Iterative Fast Fourier Transform Based Technique for Failure Correction of Dolph Chebyshev Antenna Array With Minimum Side Lobe Level

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Abstract
This paper demonstrates an approach based on iterative fast Fourier transform for the failure correction of a linear antenna array for a certain fixed minimum side lobe level with nil variation in dynamic range ratio. The criterion that there exists an inverse fast Fourier transform relationship between the array factor and the element excitations of a linear antenna array is exploited. This approach has been verified for the Dolph Chebyshev antenna array with equal spacing between the consecutive elements for different number of elements with a maximum of three failures using simulated results. The effectiveness of the above mentioned method has been utilized for broadside angle.

Keywords
Antenna Array, Failure Correction, Inverse Fast Fourier Transform

I. Introduction
Even though a high amount of directivity is achieved using linear arrays [1] with uniform spacing, they do suffer from a high side lobe level. The analysis of the radiation pattern of a linear antenna array may well result in certain inadequacies like increase in side lobe level, increase in half power beam width etc., due to the failure of one or more elements in the array in analog beam forming. But in the case of digital beam forming, the effects will not be much worse as there are chances of recalculating the beam weights of the remaining elements in such a way that the resulting radiation pattern matches closely to the desired one. These recalculations eliminate the problems of hardware replacement in arrays, which may be time consuming and also results in a decrease in cost effectiveness. This may prove quiet useful not only in military applications, but also in radar, satellite communications, where it is quite difficult to reach and replace the damaged elements. With reference to the above mentioned applications, the prime importance of antenna array synthesis as well as failure correction can be measured in terms of their effectiveness, namely, reduction in process time, low side lobe level, constrained beam width etc., As far as the past literature is concerned, there is no single effective technique which can be accepted as a perfect optimization one for the above problem. Several techniques in the past have established their supremacy in correcting the failures in antenna arrays, like optimization techniques, namely genetic algorithms, etc., [2-7]. Here, in this paper, the criterion that an inverse fast Fourier transform relationship exists between the array factor and the element excitations of an antenna array is exploited and to demonstrate this, a Dolph Chebyshev antenna array is chosen with N number of elements. The array failures are represented by a null or switching off the elements in the antenna array. The spacing between every two consecutive elements is assumed to be a constant.

II. Problem Formulation
A linear array is referred to as one, where all the elements are placed in a straight line and is considered as uniform array, when each element is supplied with a current of uniform magnitude with a progressive phase shift \( \xi \). The overall array factor \( AF \) is the sum of all the individual elements contributions [8].

The far field pattern \( FF(u) \) in the broadside plane can be given by,

\[
FF(u) = 1 + e^{j\psi} + e^{j2\psi} + \ldots + e^{j(N-1)\psi}
\]

where \( \psi = kd \cos \theta + \xi \)

The array factor can also be written in the broad side direction as

\[
AF(u) = \sum_{n=1}^{N} A_n e^{i(n-1)\phi_n}
\]

where \( \phi_n = -(n-1)kd, \ n \) is the element number in the Dolph Chebyshev array, \( k = 2\pi/\lambda \), the wave number, \( A_n \) is the excitation current amplitude of individual elements, \( d \) is the fixed spacing between consecutive elements, \( u = \cos \theta \), \( \theta \) is the angle obtained between the far field at \((r,\theta,\phi)\) and z-axis.

The array factor can also be written in the broad side direction as

\[
AF(u) = \sum_{n=1}^{N} E_n e^{i(n-1)\Phi}
\]

where \( E_n = A_n e^{i\phi_n} \)

If the array pattern is computed in \( \theta \) domain, it requires the order of \( N^2 \) operations, where \( N \) represents the number of elements in the array. The well-known Cooley Tukey FFT reduced the number of operations from \( N^2 \) to \( N \log N \). A slight modification in the
The calculation of array factor is done as shown below.

If we take

$$p = 1 + \frac{N}{2\pi} k\mu,$$

then the array factor can be transformed or mapped to the p domain from θ domain. The resulting array factor in p domain can be written as

$$AF(p) = \sum_{n=1}^{N} E_n e^{j(n-1)(p-1)(2\pi/N)}$$

(5)

In the antenna array synthesis, there exists an inverse Fourier transform relationship between the array factor and the element excitations [9]. The above written equation Eq. (5) is similar to the definition of the inverse fast Fourier transform, which shows that the array factor can be obtained through a mathematical IFFT operation on the element excitations.

The main advantage of this feature is that it requires only few lines of coding than the one without using IFFT.

The far field pattern of the linear array of N elements with uniform spacing can be summarized as the product of the array factor and the element excitations.

$$FF(u) = \text{array factor} \times \text{element excitations}$$

(6)

Since AF(u) relates with the element excitations using a discrete inverse Fourier transform, a direct Fourier transform when applied on the array factor will result in element excitations.

Another application of IFFT is that it can provide complex weights which can adaptively introduce null in the direction of interference signals while keeping the desired beam undisturbed [10]. In addition to it, the IFFT technique has been combined with evolutionary algorithms not only for array failure correction, but also for synthesis of antenna array in null steering domains [11-13].

### III. Steps involved in Array Failure Correction using IFFT

- A random excitation and a uniform progressive phase difference between N elements of a Dolph Chebyshev antenna array are applied.
- Compute the array factor using k-point inverse fft provided K>N.
- Adaptation of the array factor to the required specifications of side lobe level.
- Again compute E for the adapted array factor using k-point fft.
- The samples outside the array are made zero and the absolute value of excitations are calculated.
- The excitations which do not follow the dynamic range constraint are set to the lowest permissible value.
- Calculation of E_n.
- The steps 2-7 are repeated till the total number of iterations set is reached.

The above steps 1-8 are repeated for the Dolph Chebyshev antenna array with failure elements. In addition to it, they are repeated again with variation in the total number of elements used.

### IV. Simulated Results

The algorithm has been used for two different cases, namely one with 30 elements and the other with 40 elements. The elements used here are the isotropic antennas with uniform spacing between consecutive elements of 0.5λ along z-axis. This is done to facilitate the generation of a broad side pattern with the specified minimum side lobe level of -25 dB and a fixed dynamic range ratio of 20. The number of elements assumed to be failed in the array is fixed as 3. The goal or the objective of the simulation is to obtain a normalized power pattern which should be generated which can satisfy the minimum side lobe level restriction criterion.

Inverse fast Fourier transform used in this program is 4096 point IFFT and is padded with zeros, whenever the excitation current has less than 4096 points and a maximum of 500 iterations. The program is written using Matlab.

Fig. 2 and fig. 3 show the normalized power pattern in dB for the Dolph Chebyshev antenna array with 30 and 40 elements each. Fig. 4 shows the normalized power pattern in dB for the Dolph Chebyshev antenna array with 30 and 40 elements cases. Fig. 5(a) and fig. 5(b) shows the amplitude distribution for both the cases with a maximum of 3 failed elements in each case and whereas fig. 5(c) shows the normalized damaged power pattern again for both the cases, when number of elements are 30 and 40 respectively.

Fig. 6 shows the corrected normalized power pattern for 30-element and 40-element array respectively with 3 failed elements. Fig. 7 and fig. 8 show the minimization of side love level versus iteration numbers for both the cases.
Fig. 4: Normalized Amplitude Distribution for 30 Element (Indicated by o) and 40 Element (Indicated by +) Dolph Chebyshev Array With Minimum SLL of -25 dB and DRR of 20

Fig. 5(a): Normalized Amplitude Distribution for 30 Element Dolph Chebyshev Array With Failure at 2, 4 and 29th Elements

Fig. 5(b): Normalized Amplitude Distribution for 40 Element Dolph Chebyshev Array With Failure at 2, 4 and 29th Elements

Fig. 5(c): Normalized Damaged Power Pattern With Three Failure Elements at 2, 4 and 29th Positions for 30-element and 40-element Dolph Chebyshev Antenna Array

Fig. 6: Corrected Normalized Power Pattern With Three Failure Elements at 2, 4 and 29th Positions for 30-element and 40-element Dolph Chebyshev Antenna Array

Fig. 6, depicts that the peak side lobe level is -25.32 dB for 30-element array and -25.18 dB for a 40-element Dolph Chebyshev antenna array aimed at broadside angle.

Again from the above fig. 6, it is evident that the peak side lobe level reached almost to the desired side lobe level, which is an indication of the achievement of the expected goal. In addition to it, when the number of elements is more, the difference between the desired side lobe level and the obtained peak side lobe level is very less, when compared to less number of elements.

The time taken for the correction of the failed elements in the array of 30 elements is 0.84 seconds when using Matlab software in a PC with 2 GB RAM and 3.4GHz processor. The time difference between the correction of the Dolph Chebyshev array with 30 elements and the one with 40 elements is roughly 0.05 sec, which suggests that this technique can be used for more number of elements. A graph depicting the side lobe level variations with the number of iterations would be quiet useful in demonstrating the speed of the technique used here.

The following figures, fig. 7 and fig. 8, gives a clear indication of the number of iterations it took for the technique to obtain the corrected side lobe level in dB. These graphs are drawn with number of iterations in x-axis and side lobe level in dB in
The graphs give a clear indication that the peak side lobe level tends to remain constant within a very iterations approximately equal to or slightly more than 10 iterations.

Fig. 7: Side Lobe Level Variation in dB With Number of Iterations for 30 Element Array After Failure Correction. The Peak Side Lobe Level Obtained is -25.32 dB.

Fig. 8: Side Lobe Level Variation in dB With Number of Iterations for 40 Element Array After Failure Correction. The Peak Side Lobe Level Obtained is -25.18 dB.

V. Conclusion and Future Work
In this paper, we proposed the approach of applying inverse fast Fourier transform technique to correct the normalized power pattern for a Dolph Chebyshev antenna array giving primary importance to acceptable minimum side lobe level. Dynamic range ratio is kept fixed in order to minimize the complexity during design of feed network. The results that were obtained as an output of the simulation show a fair amount of acceptance between the desired specification of the minimum side lobe level and the obtained one. The numbers of failures were considered to be maximum three out of a maximum of 40 elements. This work can be extended to different number of failures, varying dynamic range ratio and change in number of elements considered and various steering angles.

References