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NULL SYNTHESIS OF SCANNED LINEAR ARRAY ANTENNA WITH MINIMUM SIDE LOBE LEVEL AND FIXED DYNAMIC RANGE RATIO USING ITERATIVE FAST FOURIER TRANSFORM

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Abstract

This paper presents a method based on iterative fast fourier technique for placing nulls in prescribed directions by amplitude-only control method in the radiation pattern of scanned linear array of uniformly spaced isotropic antennas with fixed dynamic range ratio of amplitude distribution and minimum peak side lobe level. Two examples have been presented, one with 20 isotropic antennas for placing two nulls and another with 22 isotropic antennas for placing wide null. Dynamic range ratio in both the cases has been fixed at 4.0.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.

Keywords:

Antenna Arrays, Fast Fourier Transform, Null Synthesis, Side Lobe Level, Dynamic Range Ratio

1. INTRODUCTION

At some applications antenna is required not to radiate to or receive from some particular directions. Thus the radiated (or received) power in (from) these directions should be negligible. Thus the radiation pattern of an antenna has to have a null in each such direction. A lot research works are going on for reducing the signal at nulls.

Null steering systems have found applications in radar, sonar and communication systems for minimizing degradation in signal-to-noise ratio performance owing to unwanted interference. It is achieved by means of arranging for a null in the antenna's polar response to coincide with the angle of incidence of the unwanted interference.

In recent years there has been a considerable interest in designing antenna array with broad null sectors [2, 20]. The need for a broad null often arises when the direction of arrival of the unwanted interference may vary slightly with time or may not be known exactly, and where a comparatively sharp null would require continuous steering for obtaining a reasonable value for the signal-to-interference ratio.

There are several methods available to form nulls in the antenna pattern in the directions of interference signals. Among these methods are the methods of controlling the amplitude and phase excitations [1], controlling the phase excitations only [4, 5, 7] or controlling the amplitude excitations of the array elements [3, 8]. The most efficient method is based on full amplitude/phase control of each element in the array.

Another method is to use either the position perturbations [6, 9, 19] or the elevations [10] of the array elements to create these nulls in the antenna pattern.

In this paper imposing of nulls in the desired directions for a scanned antenna radiation pattern has been discussed. Nulls are imposed using non-uniform excitation amplitudes for the elements. A linear antenna array structure with equal spacing between any two consecutive elements has been considered.

When the array is excited uniformly it gives high directivity but it suffers from high and unequal side lobe level. The optimal side lobe level for a given beamwidth [11] will occur when the side lobes are all equal in magnitude.

The dynamic range ratio (DRR), which is defined as the ratio between the maximum and minimum value of amplitude distribution, is usually high to obtain lower side lobe level. The higher value of DRR will complicate the design of feed network.

Soft computing tools such as genetic algorithm [12, 13], particle swarm optimization [14] have been successfully applied in the synthesis of array antenna. The article [15] presents the application of gravitational search algorithm for synthesis of reconfigurable concentric ring array antenna.

The iterative Fourier technique (IFT) has been successfully used for synthesis of low-side lobe patterns [16]. Linear array thinning using iterative Fourier techniques is reported in [17]. The property used in the iterative Fourier technique [18] is that for an array having an equal spacing of the elements, an inverse Fourier transform relationship exists between the array factor *(AF)* and the element excitations.

Because of this relationship, a direct Fourier transform performed on the array factor will generate the element excitations. The underlying approach is based on the successive use of both types of Fourier transforms.

The computational speed is very high, because the core calculations are based on direct and inverse fast Fourier transforms (FFTs).

The results presented in the paper are related to linear arrays consisting of isotropic antennas with uniform half-wave length inter-element spacing. Dynamic range ratio in all the cases has been fixed at 4.0.The objective is to generate a scanned pattern for placing nulls in prescribed directions in with minimum peak side lobe level.

2. PROBLEM FORMULATION

A linear array of N isotropic antennas [21] that are equally spaced a distance d apart along the Z-axis has been considered here. This is shown in Fig.1. The free space [21] far-field pattern $F(u)$ in the principal vertical plane for the scanned array is given by Eq.(1),

$$F(u) = \sum_{n-1}^{N} A_n e^{i\phi_n} e^{i(n-1)\frac{2\pi}{\lambda}du} \tag{1}$$

where, $\varphi_n = -(n-1)\, 2\pi/\lambda du_o$ = progressive phase

n = element number,

λ = wavelength,

A_n = excitation current amplitudes of the elements,

i = imaginary unit,

d = inter-element spacing,

$u = \cos\theta$, θ being the polar angle of far-field measured from broadside (0^o to 180^o),

$u_o = \cos\theta_o$ = scan angle.

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

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

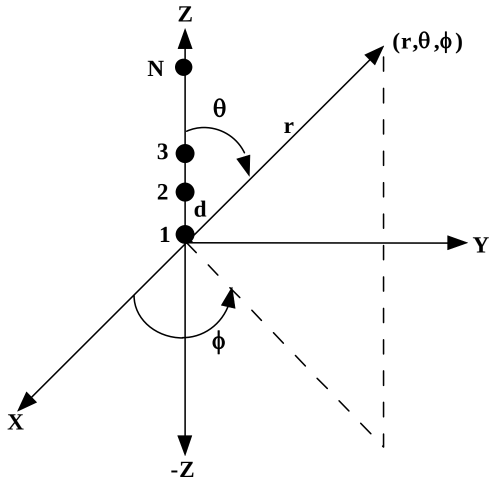

Fig.1. Geometry of a N-element linear array along the z-axis

3. FORMULATION OF FFT METHOD

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

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

where, $S_n = A_n e^{i\phi_n}$.

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

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

Through this mapping procedure, the sampling in θ domain is transformed into p domain. Note that Eq.(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 computed through an IFFT operation on the excitations S_n and the computational complexity can be reduced significantly. Nulls in prescribed directions are obtained by suppressing the energy in those directions. IFFT used in the program is 4096-point IFFT padded with zeros if excitation current has less than 4096 points.

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

The different steps involved in implementation of the iterative Fourier technique algorithm [18] for the synthesis of low side lobe patterns for linear arrays with fixed dynamic range ratio are described as follows:

Step 1: Start the synthesis using a uniform random excitation A_n between 0 and 1 and uniform progressive phase φ_n for N elements. Calculate, $S_n = A_n e^{i\phi_n}$.

Step 2: Compute AF from S_n using a *K-point* inverse FFT, with $K > N$.

Step 3: Adapt AF to the prescribed side lobe and null constraints.

Step 4: Compute S_n for the adapted AF using a *K-point* direct FFT.

Step 5: Truncate S_n *from K* samples to N samples by making zero all samples outside the array and then calculate absolute value A_n normalized to one from S_n.

Step 6: Set the magnitude of the excitations A_n violating the amplitude dynamic range ratio constraint to the lowest permissible value. Recalculate S_n.

Step 7: Repeat Steps 2-6 until the prescribed side lobe and null requirements for AF are satisfied, or the allowed number of iterations is reached.

4. SIMULATION RESULTS

Two examples have been presented here; one with 20 isotropic antennas for placing two nulls and another with 22 isotropic antennas for placing wide null. Isotropic antennas are uniformly spaced 0.5λ apart along Z-axis in order to generate a broadside pattern with minimum side lobe level and specified dynamic range ratio of 4.0. The goal is to find the set of excitation that will satisfy the requirement as stated above.

IFFT used in the program is 4096-point IFFT padded with zeros if excitation current has less than 4096 points.

The computation time is measured with a PC with Intel core2 duo processor of clock frequency 2GHz and 1GB of RAM. Program is written in Matlab. Synthesis using 4096-point IFFT takes 21.085954 seconds and 22.889509 seconds only for the above said two examples respectively. Program is run for 3000 iterations for both the cases.

Fig.2 to Fig.5 shows normalized absolute power pattern in dB, normalized amplitude distribution, minimization of side lobe level versus iteration and phase distribution respectively for 20 elements linear array for placing two nulls with side lobe level of -30dB.

Fig.6 to Fig.9 shows normalized absolute power pattern in dB, normalized amplitude distribution, minimization of side lobe level versus iteration and phase distribution respectively for 22 elements linear array for placing wide null with side lobe level of -28dB.

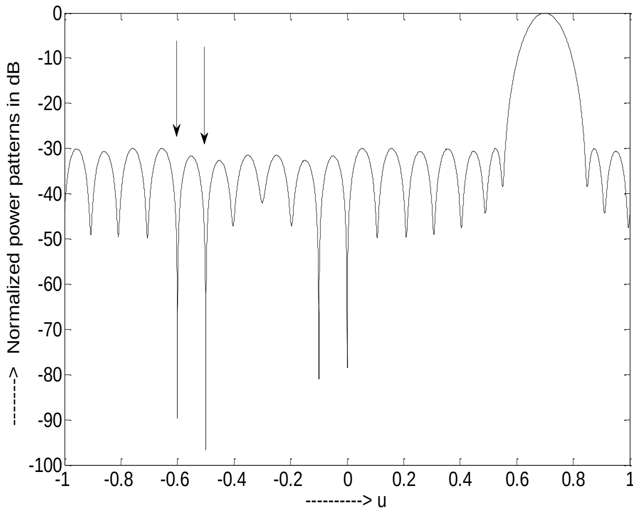

Fig.2. Normalized Power Pattern for 20 element linear array scanned at u= 0.7 with two prescribed nulls at u= -0.6 of depth -89.7706 and u = -0.5 of depth -96.7835, SLL -30dB &DRR= 4

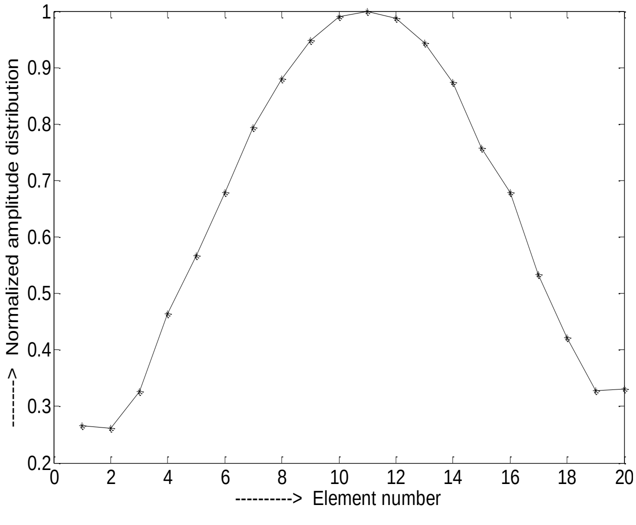

Fig.3. Normalized amplitude distributions for 20 element linear array scanned at u= 0.7 with two prescribed nulls at u= -0.6 of depth -89.7706 and u = -0.5 of depth -96.7835, SLL -30dB and DRR= 4

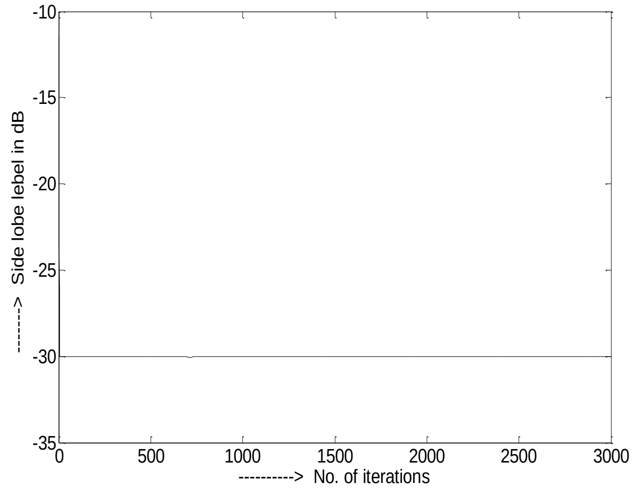

Fig.4. Minimization of Side Lobe Level to -30dB 20 element linear array scanned at u= 0.7 with two prescribed nulls at u= -0.6 of depth -89.7706 and u = -0.5 of depth -96.7835 & DRR= 4

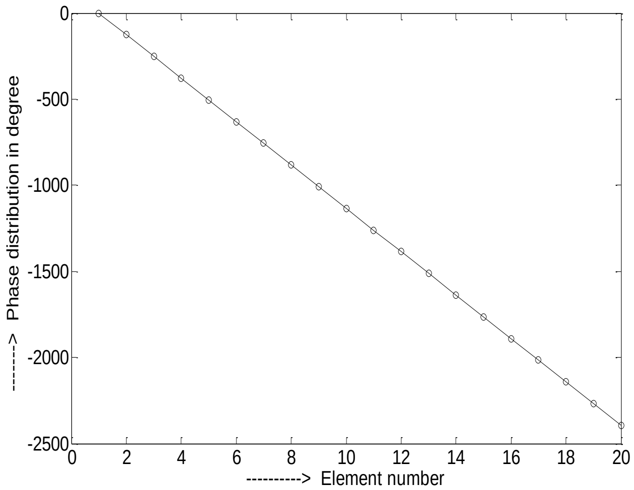

Fig.5. Phase distributions for 20 element linear array scanned at u= 0.7 with two prescribed nulls at u= -0.6 of depth -89.7706 and u = -0.5 of depth -96.7835, SLL -30dB and DRR= 4

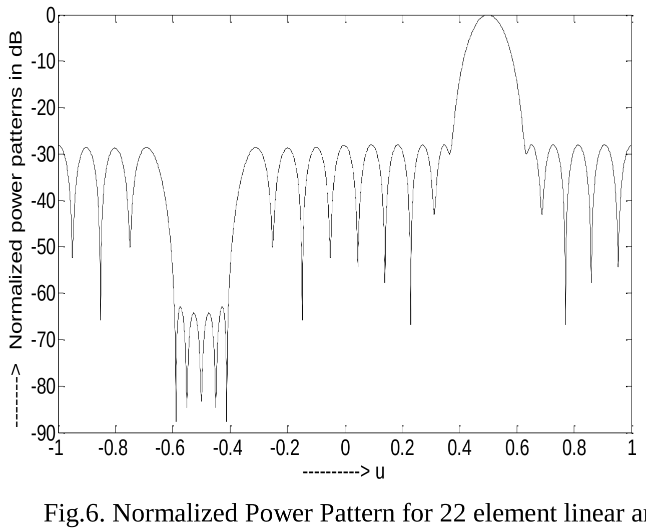

Fig.6. Normalized Power Pattern for 22 element linear array scanned at u = 0.5 with wide null between u = -0.5 and u = -0.4 of depth -64.55dB, SLL -28dB and DRR= 4

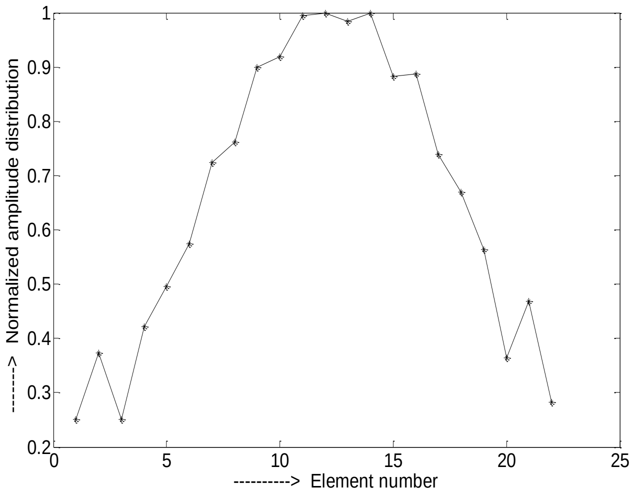

Fig.7. Normalized amplitude distributions for 22 element linear array scanned at u = 0.5 with wide null between u = -0.5 and u = -0.4 of depth -64.55dB, SLL -28dB and DRR= 4

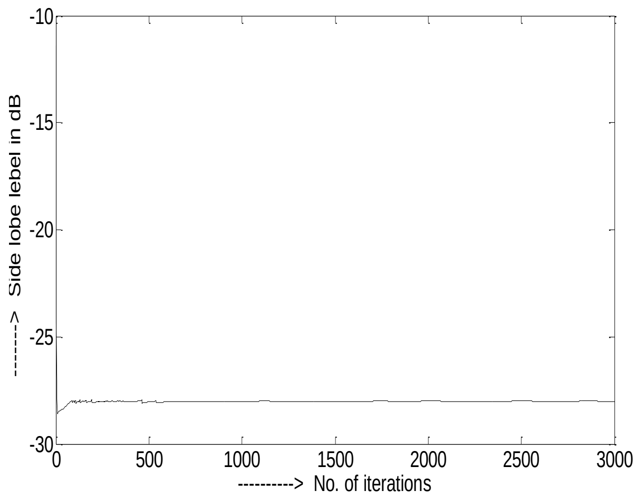

Fig.8. Minimization of Side Lobe Level to -28dB for 22 element linear array scanned at u = 0.5 with wide null between u = -0.5 and u = -0.4 of depth -64.55dB and DRR= 4

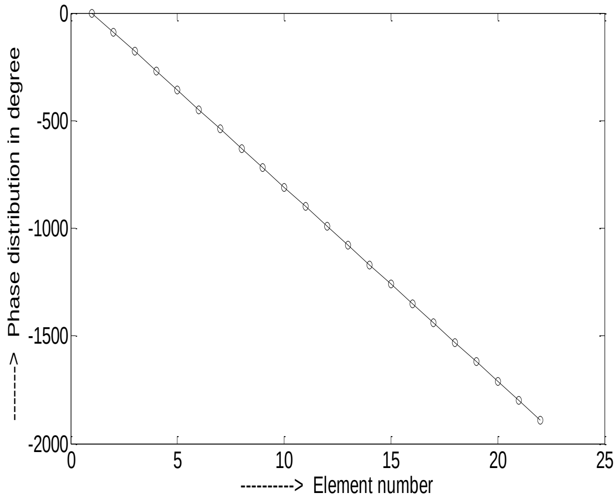

Fig.9. Phase distributions for 22 element linear array scanned at u = 0.5 with wide null between u = -0.5 and u = -0.4 of depth -64.55dB, SLL -28dB and DRR= 4

5. CONCLUSION

In this paper, iterative Fast Fourier Transform is used as an alternative to other optimization algorithms for placing nulls in prescribed directions in the radiation pattern of scanned linear arrays with minimum side lobe level and fixed dynamic range ratio. Results clearly show a good agreement between desired and obtained specifications. The major advantage of using FFT is to reduce computation time while considering array of any size. Low value of dynamic range ratio is required to minimize the complexity in designing a feed network.

Results for linear arrays of isotropic antennas have illustrated the performance of this proposed technique.

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