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Null Steering in a Large Antenna Array using the Elements Positions of the Subarray

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1. Introduction

Array antennas constitute one of the most versatile classes of radiators due to their capacity for beam shaping, beam steering, and high gain. The problem of synthesizing the antenna pattern with controlled nulls to eliminate unwanted interference sources has been widely addressed in the literature [1-8]. Null steering methods in phased array have found wide applications in modern radar and sonar communication systems. They represent generalization of classical pattern synthesis techniques, where the main beam shape and sidelobe reductions are more important than the detailed sidelobe structure. 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 [1,2], controlling the phase excitations only [3-7], or controlling the amplitude excitations of the array elements [8]. Each of the methods has its specific advantages and disadvantages. In recent years, the null-steering problem is cast as a non linear optimization problem, in which the excitation amplitudes, phases, and/or element positions are taken as the optimization parameters. The objectives then are to steer the nulls in the directions of interferences, while keeping the sidelobes below certain levels. The most widely used optimization techniques in antenna array pattern synthesis are steepest decent algorithm [4], genetic algorithms [9], modified touring ant colony optimization [10], modified tabu search algorithm [11], differential evolution algorithm[12], and memetic algorithms [13].

The alternative method is to use either the position perturbations [14-16] or the elevations [17] of the array elements to create these nulls in the antenna pattern. However, these two methods require servo motors to move every element in the array. To reduce the number of mobilized elements in a large array and to effectively increase the array robustness, the method of controlling only the element positions of partially adaptive array is very useful.The method is based on dividing a large array into two contiguous subarrays symmetrical about the center of the array. It is shown that the method utilizes the fact that the position perturbations of those elements of the subarray which are located closely around the center of the array contribute more to the null formation. This paper presents a new and fast method of forming deep nulls in the antenna pattern in the directions of interferences by controlling partially the positions of a set of elements of a larger array. The subarray is created with a reasonable number of elements around the center of the array. The position perturbation of the subarray elements which form the nulls are obtained using the linearized method of the small phase perturbations in which two terms of Taylor expansion of the phased term is considered [18]. The results demonstrate the capability of this technique to form nulls in the required directions.

2. Analysis

Consider a linear array of N isotopic equispased elements, which has the pattern

$$F_o(u) = \sum_{n=1}^{N} a_n e^{jd_n(u-u_s)}. \quad (1)$$

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Where a_n and d_n are the excitation and the location of the n^{th} element respectively; $u = k\sin(\theta)$, where θ is the angle measured from the broadside direction and $k = 2\pi/\lambda$ is the wave number; $u_s = k\sin(\theta_s)$ is the steering angle of the main beam from the broadside.

The array is divided into two set of elements around the array center to form two subarrays as shown in Fig. 1.The inner subarray with elements close to the array center will have L elements, while the outer subarray will have $N-L$ elements respectively. The positions of the second set of elements of the outer subarray are kept unchanged from their original locations. The positions of L elements of the inner subarray will be perturbed and the contribution of each element position of this set to M null locations can be calculated using the standard perturbation theory namely, replacing d_l in equation (1) by $d_l + \delta_l$, where δ_l is the small position perturbation along the array line of the l^{th} element of the inner subarray. The perturbed pattern evaluated at the null locations $F_p(u_m)$ corresponding to the element position perturbations of L elements of the subarray is

$$F_p(u) = \sum_{k=1}^{N-L} a_k e^{jd_k(u_m - u_s)} + \sum_{l=1}^{L} a_l e^{j(d_l+\delta_l)(u_m-u_s)} = 0, \qquad m = 1,2,...,M \tag{2}$$

The first term in (2) represents the antenna pattern of the outer subarray, while the second term represents the antenna pattern when the element positions of the inner subarray are perturbed. When the element position perturbations of the subarray elements are small compared to the interelement spacing, then the second term in (2) can be linearized using the first two terms of Taylor expansion :

$$F_p(u_m) = \sum_{n=1}^{N} a_n e^{jd_n(u_m-u_s)} + j\sum_{l=1}^{L} a_l\, \delta_l\, (u_m - u_s)\, e^{jd_l(u_m-u_s)} = 0 \qquad m = 1,2,..,M \tag{3}$$

This constitutes a system of M equations where the number of unknowns is in fact greater than the number of equations (L >> 2M). A complete set of linear unbiased estimates for the unknowns δ_l can be found using the assumption that the position perturbations introduced to the one of the subarry elements of the antenna array are small in the mean square sense [14].

In general, a subarray with the reasonable set of elements around the center of the array can perform a limited number of nulls in the antenna pattern in any direction in the sidelobe regions. The number of nulls should always be less than the number of selected elements.

3. Results

To validate this approach, few illustrative examples of prescribed nulls have been simulated. The computations were performed for an array of 20 elements with half wavelength spacing and with the main beam directed toward the broadside. The nulls are formed by controlling the positions of the subarray elements. In Fig. 2 we show the original and the perturbed pattern for two nulls imposed at 15^0 and 20^0 corresponding to the peaks of the second and the third sidelobes. Fig. 2 (a) and Fig. 2(b) show the perturbed patterns for the case when the positions of 14 and 12 elements of the inner subarray are perturbed, respectively. The results show that even in the case where the number of nulls is large, the element position perturbations of the selected subarrays using this method produces deep nulls. The initial levels at the nulls locations at 15^0 and 20^0 have been reduced by more than 52 dB and 24 dB for 14 elements subarray; also 37 dB and 26 dB for 12 elements subarray respectively.

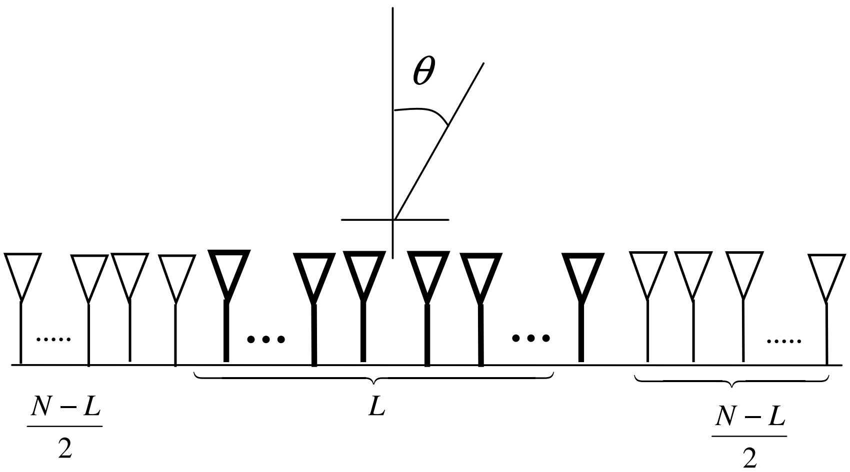

Fig. 1 Large phased antenna array divided into two contiguous subarrays The elements of the inner subarray (bold) are used for null steering

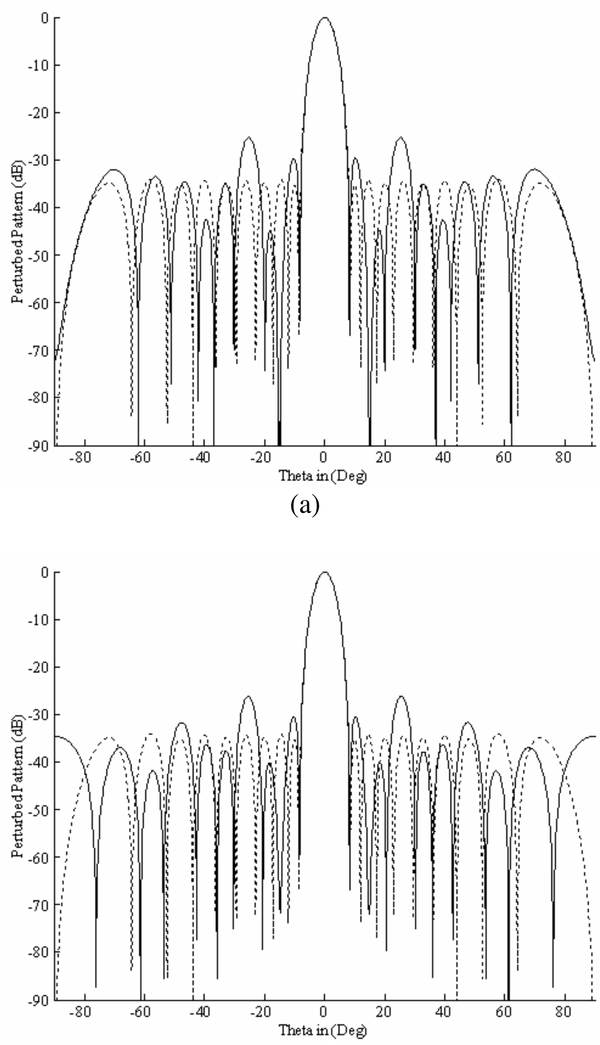

Fig.2. Perturbed pattern (solid) with two nulls imposed at 15^0, and 20^0 and original pattern (dotted) using the position perturbations for (a) 14 elements. (b) 12 elements.

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4. Conclusion

W e have described a method of null steering in the antenna pattern of a phased array. The method is based on dividing a large array into two contiguous subarrays symmetrical about the array center. Only the element positions of one of the subarrays are used to perform the nulling., as a result the amount of computation is reduced. In addition, the number of mobilized elements is less.

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