Planar Array with Optimized Perimeter Elements

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Abstract. To effectively detect the targets in any direction, the radar antenna should be in the form of a planar array that has a large number of elements. In such a case, partially adaptive planar arrays, where only a few elements are adaptive, are often necessary to reduce the system's cost and increase the speed of the tracking capability. In this paper, only the perimeter elements of the planar arrays are selected to be adaptive while maintaining the good radiation characteristics as that of the fully adaptive planar arrays with, of course, lower cost and fewer RF components. Unlike a previous method that consists of optimizing only two edge elements in the linear arrays, the proposed planar array with optimized perimeter elements is quite sufficient to provide enough degrees of freedom to control the sidelobe pattern and place the desired nulls efficiently. Simulation results show that the required radiation pattern with asymmetric sidelobes and desired nulls can be obtained by optimizing only the perimeter elements of the planar arrays, while the interior elements are left unchanged.

Keywords: Planar arrays, perimeter elements control, asymmetric sidelobes, null steering, convex optimization.

1 Introduction

In many applications of the phased array antennas, planar arrays are more preferable than the linear arrays since they have the capability to scan the mainbeam of the array pattern toward any direction. Such applications include tracking radar, searching radar, remote sensing, and wireless communications. Although the uniformly excited and equally spaced planar arrays have many good practical features such as low cost and simplified feeding network, they cannot provide sidelobe levels (SLLs) below -13.2 dB, which is relatively high and could cause many problems. One effect of high sidelobes is the inability to detect the targets due to the strong ground clutter and/or high interference environment. In order to suppress these clutter echoes, the array pattern should be designed with low sidelobes or asymmetric sidelobes [1],[2]. However, an increase in the width of the mainlobe is unavoidable as the cost of obtaining low sidelobes. In an attempt to maintain the mainlobe undistorted while suppressing the sidelobes, a simple analytical method was presented in [3] where the amplitude and phase excitations of the two side-elements in the linear array are adjusted analytically to obtain a wide angular null in the direction of unwanted interfering signals. That method [3] is extended here to the planar arrays where the amplitude and the phase excitations of only the boundary elements are modified to a certain value, which is, of course, lower than that of the interior elements to achieve sidelobe reduction [4]. However, with such analytical procedures, the requirements of imposing some necessary constraints on the resulting pattern were not possible, and the

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determined values of the amplitude and phase of the excitations may not be those that give the optimum pattern.

Many optimization techniques such as genetic algorithm [5], particle swarm optimization [6], improved nonlinear least-square method [7], the differential evolution algorithm [8], and others [9] have also been used. The purpose was to design the planar arrays with desired radiation characteristics such as minimum SLL, controlled nulls, and narrower beamwidth. Most of these methods use all the number of the array weights in the optimization process, and thus, they suffer from high computational complexity and low convergence speed, especially for large planar arrays. The complexity and the speed of the optimization methods can be reduced significantly by optimizing only a few numbers of the array elements while holding the rest elements unchanged [10],[11].In [10], a single wide null in the linear array pattern was obtained by optimizing the amplitude and phase excitations of the two edge elements only, while in [11], multiple wide nulls were obtained by optimizing a subset of the whole array. The subset is chosen to comprise the most effective elements in the linear array.

In this paper, the phase and amplitude excitations of the elements at the perimeter of the planar arrays are optimized using the convex optimization technique [12]. The optimization process was carried out with specific constraints to get a radiation pattern, having the required characteristics such as asymmetric low sidelobe structure, narrow beamwidth, and few nulls that can be directed to some pre-defined directions. In contrast to the traditional techniques in which all the array elements need to be controllable, the proposed method enjoys a faster convergence rate since the interior elements are made constant and maintaining a good performance.

2 Planar array with optimized perimeter elements

The planar array considered here is of rectangular shape that is composed of M columns and N rows of isotropic elements which are spaced by$d = \lambda/2$ alongeach of the x and y directions. The array factor of such array is given by

$$AF(\theta,\phi) = \sum_{n=1}^{N}\sum_{m=1}^{M} w_{nm} e^{j\frac{2\pi d}{\lambda}[\left(n-\frac{N+1}{2}\right)(\sin(\theta)\cos(\phi)-\beta_x)+\left(\mathrm{m}-\frac{\mathrm{M}+1}{2}\right)(\sin(\theta)\sin(\phi)-\beta_y)]} \qquad (1)$$

where λ is the wavelength at the operation frequency,θ and ϕ are the elevation, and azimuth angle, respectively, $\beta_x = \sin(\theta_0)\cos(\phi_0)$, $\beta_y = \sin(\theta_0)\sin(\phi_0)$ are the progressive phase shifts in the x and y directions, respectively. Such phase shifts are required to scan the mainbeam to the (θ_0, ϕ_0)direction, and $w_{nm}$is the complex weight (amplitude and phase) of the *(n,m)th* array element. The array factor in (1) shows a fully adaptive 2-dimensional array in which all the elements can be adjusted, through varying the weightsw_{nm}. Thus, the array requires a relatively complex feed network that can have up to N×M attenuators and phase shifters. Furthermore, to meet the required characteristics of the radiation pattern, it is necessary to impose some constraints on the parameters of the obtained radiation pattern, which influences the weights of the array elements leading to an increase in the complexity of the adaptive system. Therefore, it is necessary to control a smaller number of array elements, especially when large planar arrays are required to be implemented, and faster adaptation is desirable.

This work proposes a solution to the above problem. The weights of the interior $(N-2)\times(M-2)$ elements of the array are kept constant, i.e.,$w_{nm} = 1$ out of the total array ofN×M elements. The elements at the perimeter of the array are considered adjustable (or adaptive) subject to some imposed constraints. Therefore, the array factor in (1) can be arranged in the following form:

$$AF(\theta,\phi)=\underbrace{\sum_{n=2}^{N-1}\sum_{m=2}^{M-1} e^{j\frac{2\pi d}{\lambda}\left[\left(n-\frac{N+1}{2}\right)(\sin(\theta)\cos(\phi)-\beta_x)+\left(m-\frac{M+1}{2}\right)(\sin(\theta)\sin(\phi)-\beta_y)\right]}+}_{interiorelements}$$

$$+\underbrace{\sum_{m=1}^{M}(w_{1m}\{.\}+w_{Nm}\{.\})+\sum_{n=2}^{N-1}(w_{n1}\{.\}+w_{nM}\{.\})}_{Perimeterelements}(2)$$

Where $\{.\}$ stands for the exponential term described by the first term of Eq.2. The array factor due to the elements at the perimeter (given by the lower term of (2))is expressed by summing the contributions of the elements at two rows and two columns. For the elements on the two rows, the value of n is set to $n=1$ and then$n=N$, while the value of m is allowed to vary from *1* to *M*. Similarly, for the elements in the two columns, the value of *m* is set to $m=1$ and $m=M$, while the value of n is allowed to vary from 2 to *M-1*.
By comparing (1) and (2), it is clear that the number of the adjustable weights, $\mathrm{w_{nm}}$, has been reduced from $\mathrm{N}\times\mathrm{M}$ in the fully adaptive planar array to only $2(N-1)+2(M-1)$in the proposed planar array. Unlike the control methods of the two edge elements that were presented in [1],[3],[4], [10] and [11], the proposed planar array has enough degrees of freedom to efficiently accomplish low SLL and null controls as will be shown in the simulation results.
The optimization problem is formulated as the determination of the complex weights of the perimeter elements such that the resulting radiation pattern is constrained by one or more of the following:

$|AF(\theta,\phi)|$ $is\ minimum$ (3)
Subject to $AF(\beta_x,\beta_y)=1$ (4)
$|AF(\theta_i,\phi_i)|\leq SLL_i^{left}\theta_i\in(\Omega_{BW},180)$ (5)
$|AF(\theta_i,\phi_i)|\leq SLL_i^{right}\theta_i\in(0,-\Omega_{BW})$ (6)
$|AF(\theta_j,\phi_j)|\leq Null_j j=1,2,\dots,J$ (7)

where SLL_i^{left}, $SLL_i^{right}{}_i$ are the required sidelobe levels on the left and right sides of the mainbeam in the proposed array pattern, $Null_j$ is the required number of the nulls toward interfering signals, *J* is the total number of the interfering signals, and Ω_{BW} is the required half-beamwidth in the elevation plane. The constraint in (4) aims at preserving the unit gain in the look direction, while the constraints in (5), (6), and (7) are for obtaining the required asymmetric sidelobe levels and null directions.

3. Simulation Results

In this section, three examples are presented and investigated by simulations to assess the performance of the proposed technique. In the first example, a uniform planar array having 36 isotropic elements (*N*=M=6)that are spaced by $\lambda/2$ is assumed. The required half-power beamwidth (HPBW) of the radiation pattern of the proposed array was chosen tobe 17^o, ($\Omega_{BW}=8.5^o$). As for a uniformly excited planar array having 6x6 elements, the HPBW is also 17^o, then, the obtainableHPBW of the radiation pattern of the optimized array is constrained to be equal to that of the uniform planar array. The direction of the desired signal is assumed to be known and equals to 90^o.

In this example, the capability of the proposed planar array for dealing with multiple interfering signals is demonstrated. An adverse interference is assumed, where there are eight interfering signals are impinging on the proposed array from the pre-assumed arbitrary directions of $\phi = 0^o$, and $\theta$is at 20^o, 37^o, 63^o, 75^o, 115^o, 140^o, 155^o, 170^o. In this case, the weights of the perimeter elements are varied so that the resulting array factor complies with the imposed constraints according to (3), (4), and (7). The null levels are set below $\mathrm{Null_j} = -80\mathrm{dB}$. Figure1 shows the radiation pattern of the proposed planar array with optimized perimeter elements according to the above-mentioned constraints. For comparison purposes, the radiation pattern of the fully optimized planar array is also shown in Figure1. It is found that the pattern of the proposed planar array is capable to accurately allocate all the desired nulls with required depths toward the eight interfering signals. The sidelobes are below –15.32dB while the half-power beamwidth is at 17^o which is the same as that for the uniformly exciting array. Here, in this case, the number of the optimized elements at the perimeter is 20, whereas the number of the interior elements that remain unchanged is 16 elements. As seen from Figure1, the number of degrees of freedom is quite sufficient to obtain a radiation pattern having all the required nulls. The complex weights (in magnitude and phase) that correspond to the elements in the fully optimized planar array and those of the proposed array are shown in Figure 2 and Figure 3, respectively. It is seen from Figure 3, that only the magnitudes and the phases of the 20 perimeter elements are adjusted, whereas the excitations of the 16 interior elements are kept constant at the same value.

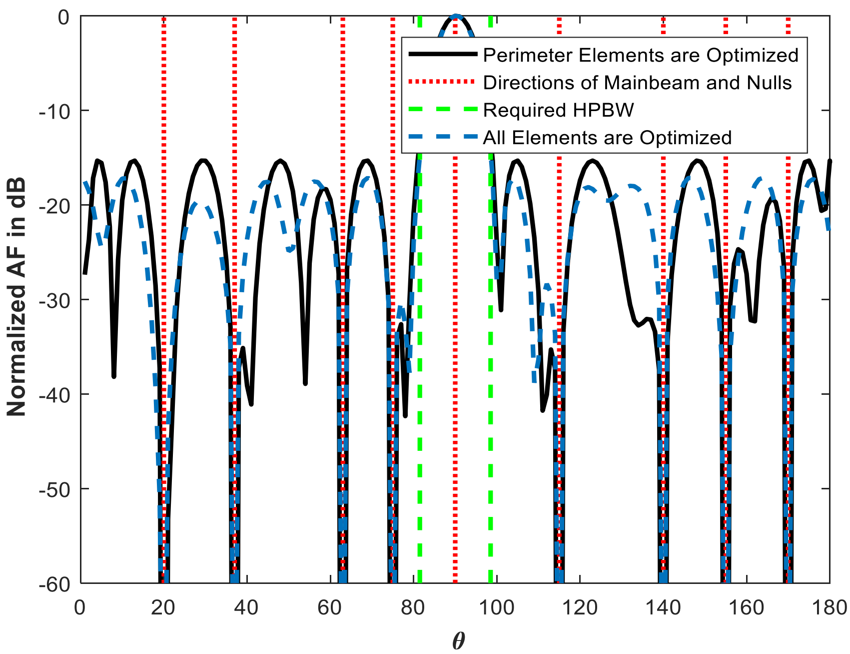

Fig.1. The radiation pattern of the proposed6x6 element arraycompared with that of the fully optimized array under the constraints of generating 8 different nulls.

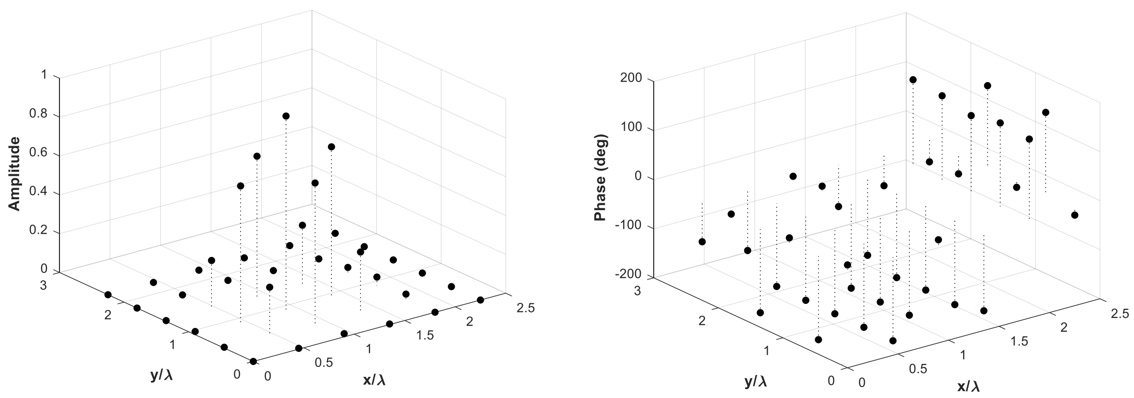

Fig.2. The excitations (amplitude and phase) of the fully optimized 6x6 element planar array whose radiation pattern is shown in Fig.1.

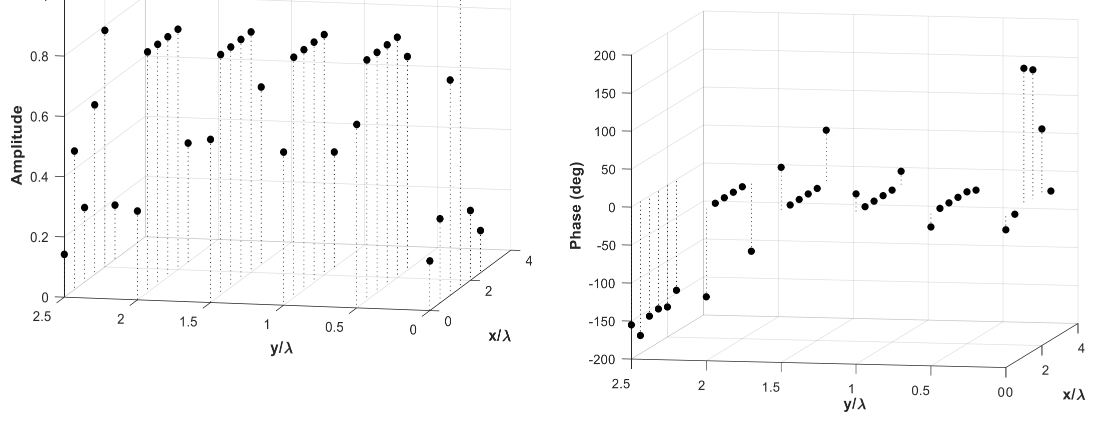

Fig.3. The excitations (amplitude and phase) of the 6x6 element proposed planar array pattern whose radiation pattern isshown in Fig.1.

In the second example, the weights of the elements at the perimeter of the proposed array are optimized according to (3), (4), (5), (6) and (7) such that the corresponding radiation pattern has asymmetric sidelobes, i.e., low sidelobe level towards the ground direction and a relatively higher sidelobe level on the sky direction for the purpose of the desired nulls at the wanted places. The half-power beamwidth is at 17^o which is the same as that obtainable from the uniformly excited planar array.

In the third example, the weights of the elements at the perimeter of the proposed array are optimized according to (3), (4), (5), (6) and (7) such that the corresponding radiation pattern has equal sidelobe level at -20 dB (i.e., the values of SLL_i^{left} and SLL_i^{right} are both set to -20 dB) and there are two nulls at $\phi = -30^o, \theta = 80^o$ (i.e., $u_x = 0.852, u_y = -0.492$) and $\phi = 45^o, \theta = -70^o$ (i.e., $u_x = -0.664, u_y = -0.664$). Figure 6 shows the radiation pattern of the proposed array. For comparison purposes, the radiation pattern of the uniformly excited planar array is also shown in Figure 6. It is obvious that the required sidelobe level (of -20 dB) and the desired two nulls have been efficiently achieved by optimizing the excitations of only 20 elements at the perimeter of the array.

Finally, the computational complexity, in terms of the required number of the variable phase shifters and attenuators for the proposed partially adaptive planar array in comparison with that of the fully adaptive planar array is investigated. Table I shows the total number of the adjustable elements in the fully adaptive planar array (column 1), and the number of the adjustable (column 2) and non-adjustable (column 3) elements in the proposed array. The reduction in the complexity may be defined by the ratio of the number of the inner elements (whose excitations are kept fixed) to the total number of elements:

$$Complexity\ Reduction = \frac{(N-2)(M-2)}{N \times M} \quad (8)$$

Generally, it is found that a better reduction in the complexity is achieved for larger arrays, as shown in the last column of Table 1.

suppressing the ground clutter. It's also assumed to have a null at $\theta = 20^o$. In this example, the value of SLL_i^{left} and SLL_i^{right} is set to -10 dB and -40 dB, respectively. The sidelobe regions of both sides of the mainbeam are bounded by $[0, -\Omega_{BW}]$ and $[\Omega_{BW}, 180^o]$. Figures 4 and 5 show the radiation pattern and the corresponding weights of the proposed array, respectively. From these figures, it is obvious that the optimized pattern of the proposed array meets the required goals in accomplishing the asymmetric sidelobes in the specified plane and, at the same time placing

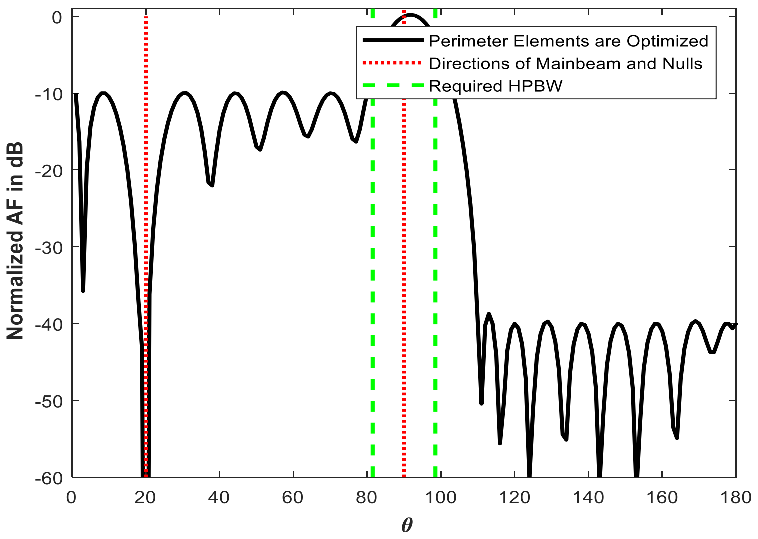

Fig.4. The optimized radiation pattern of the proposed 6x6 element planar array under the constraint of having asymmetric low sidelobes.

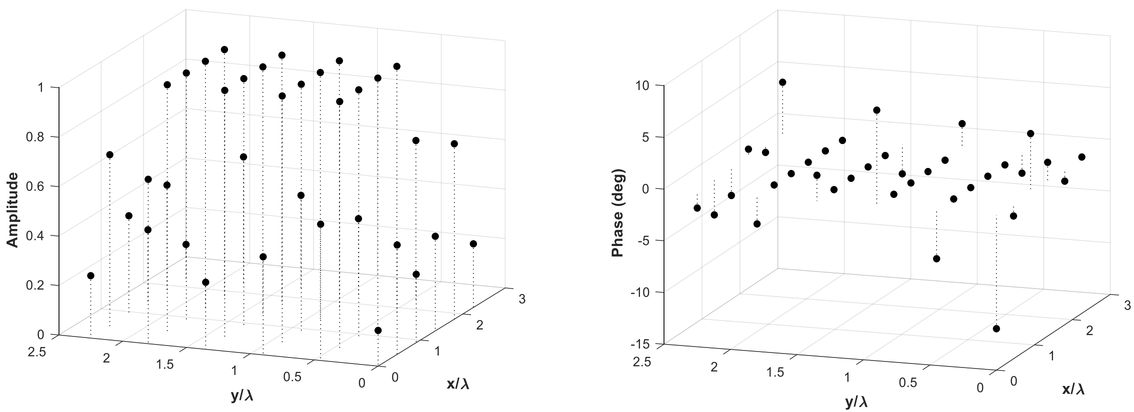

Fig.5. The excitations (amplitude and phase) of the proposed 6x6 element planar array whose radiation pattern is shown in Fig.4.

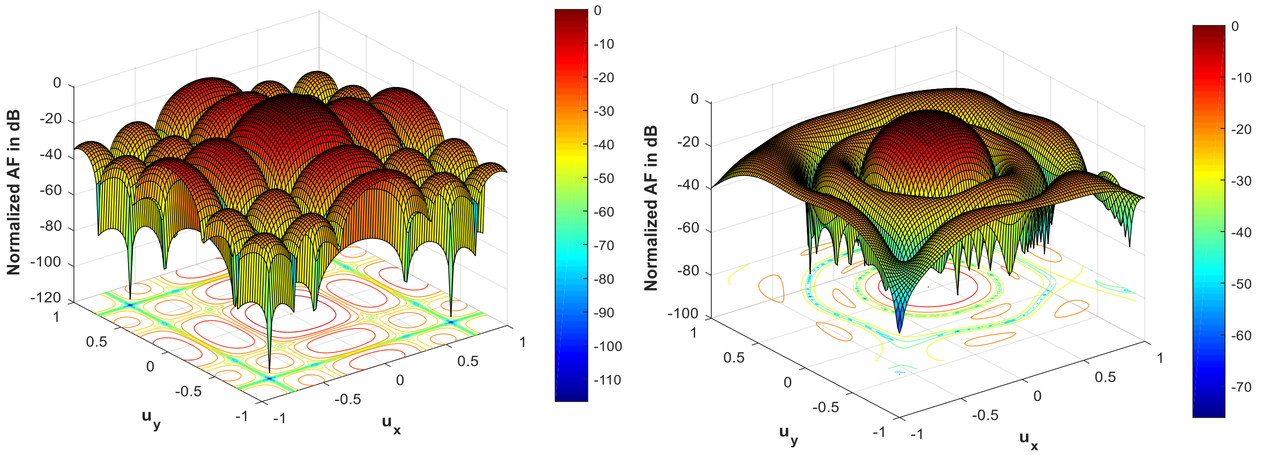

Fig.6. The optimized radiation patterns of the proposed 6x6 array (right) compared to the radiation pattern of the uniformly excited 6x6 array (left).

Table 1. The computational complexity of the proposed partially adaptive planar array compared to fully optimized planar arrays

Total number of elements	No. of perimeter elements	No. of interior elements	Complexity reduction %
5x5	16	9	36
10x10	36	64	64
15x15	56	169	75.1
20x20	76	324	81
25x25	96	529	84.7

4. Conclusions

Convex optimization has been used to optimize the excitations of only the perimeter elements of the planar array subject to low asymmetric sidelobes and controlled nulls. In addition, the required beamwidth of the proposed planar array is also included in the weight constraints. These good radiation characteristics have been successfully obtained with lower cost and simpler feeding network as compared to the fully optimized planar arrays. Further reduction in the cost and the computational complexity can be obtained with larger planar arrays where the ratio of the number of the perimeter elements to the total number of the planar array decreases as the array size increases. Moreover, the convergence speed of the optimizer in the proposed planar array is much faster than that of the conventional fully optimized planar arrays.

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