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Optimum Null Steering Techniques for Linear and Planar Antenna Arrays using Genetic Algorithm

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ABSTRACT

Null steering to cancel interference at a given directions in adaptive arrays could be achieved efficiently using genetic algorithm (GA). Major deviations in the beam steering direction and large perturbation in the side lobe level could be the main limitations for placing nulls in the far field pattern. In this paper, null steering techniques for Dolph-Chebyshev and thinned antenna arrays using GA are studied. Linear arrays composes of 20 and 40 elements are designed. Single, multiple, symmetric or adjacent to the main beam interference scenarios are considered. Various results are presented and discussed to show the advantages and limitations for all null steering techniques. Also, a novel GA/MoM code is implemented to suit any optimization problem involving wire antennas. This new code is used to fix nulls for an example of planar array with (5×10) short dipole elements.

I. Introduction

Adaptive nulling approach is a viable mean of quickly placing a null in the sidelobes of an array antenna. Usually, it is required to steer the array nulls precisely to the directions of interfering signals with prescribed amplitudes. Different pattern synthesis techniques are used to allow the placing of one or more nulls at specified jamming directions. Recently, genetic algorithm proves to be very efficient for the pattern synthesis designs. Nulls control in an antenna arrays can be achieved with different techniques such as: Perturbation of elements positions (variation of geometry), [1] and [2], phase control of each element (variation of excitations phases), [3], amplitude control of each element (variation of excitations amplitudes), [4], and combination of amplitude and phase controls of each element, [5].

In most of the previous work, Dolph-Chebyshev arrays are used for null steering purposes [1]-[5]. Arrays of this type have a drawback of continuous adjustment of complex excitation coefficients. However, the GA thinned array is based upon switching the array elements on and off. It has been shown that thinned arrays can replace Chebyshev arrays to be used in switched beam antennas [6]. In this paper, thinned array optimized for minimum peak side lobe level (psll) are used as the initial pattern to be steered for nulls. The objective of this paper is to apply GA for various null steering techniques for both linear and planar arrays as will be discussed in section II. In section III, a new program of GA in conjunction with NEC is developed such that numerical cost functions can be applied for linear and planar arrays or any type of wire antenna arrays. Numerical results and discussions are carried out in section IV. Finally conclusions are derived in section V.

II. Genetic Algorithm for adaptive antenna array

There are many approaches to realize adaptive antennas. One of these approaches is to use genetic algorithm to adjust the spacing between elements, phase and amplitude weights of excitations. The main beam is required to be directed to the desired signal and nulls to sources of interference. The following subsections are describing the principles of adaptive nulling optimization using GA's.

II.1. Element position perturbation technique

Null steering in linear arrays can be achieved by element position perturbations [1], [2] as an alternative to the costly choice of amplitude and phase weighting control techniques. This technique is based on the assumption of relatively small element position perturbations so that an optimized solution can be formulated. The problem formulation begins with the array factor of a linear array of N equispaced elements as shown in the following equation.

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

where d_n is the distance from the array center to nth element, $u=\beta sin\theta$ and θ is the angle measured from the broad side. The elements may now be perturbed along the axis of the array by ΔS_n. The values of the perturbation are small compared to the interelement spacing. The positional perturbations are optimized within a variable constraint range to maintain the main beam directions. The perturbed pattern can be given by

$$AF(u)=\sum_{n=1}^{N} a_n . cos[d_n(u-u_s)+\Delta S_n(u-u_s)] \qquad (2)$$

The GA's operations take place to the problem to give the optimum values of the positional perturbations (ΔS_n). The fitness function that is chosen in this problem to maintain the main beam direction and to have imposed null at the jamming direction can be expressed as

$$Fitness=\frac{AF(u_s)}{AF(u_m)} \qquad (3)$$

Where, $AF(u_s)$ is the value of the array factor in the main beam direction. $AF(u_m)$ is the value of the array factor at each of the desired null positions. One of the advantages here is that the phase shifters can be used solely for steering the main beam.

II.2. Phase control technique

Another adaptive algorithm modifies the quantized phase based on the minimization of the total output power of the array.

$$AF(u)=\sum_{n=1}^{N} a_n . cos((n-0.5)(ud+\Delta_s)+\tau_n) \qquad (4)$$

where u as defined before, Δ_s is the main beam steering phase and τ_n are the null steering values of phase settings are which real and continuous as a multiple of 2π. Using a limited number of digital phase shifter bits solves the problem of main beam distortion. The designer requires determining the range of τ_n that allows formation of nulls on the sidelobes without significant impact on the main beam. A study for the number of bits and τ_n phase settings will be discussed in the numerical results section. Fitness functions that reduce the noncoherent output of the array at the places of null similar to (3) should be used. One of the limitations of this technique is that it places a null at one angle and it causes the sidelobe at the symmetric location to go up.

II.3. Amplitude control technique

A third technique could be used to achieve null steering is the control of the elements amplitudes for thinned arrays. Thinning an array means turning off some elements in uniformly spaced or periodic array to create a desired amplitude density across the aperture. Consider a non-uniform equispaced linear array composed of N isotropic elements placed along the array axis. Genetic algorithm can be used to minimize the peak side lobe level in the range outside the main beam and fixing multiple (*M*) nulls at the same time. In this case the fitness function could be written:

$$Fitness = 20 \ \ log_{10}(AF(u) + \sum_{m=1}^{M} AF(u_m)) \qquad (5)$$

where $AF(u)$ is the value of the array factor without any null as in equation (1) and $AF(u_m)$ is the value of the array factor with every precised null position. For this technique, a chromosome is a vector containing all the genes, the gene is only one bit. The genes (bits) represent the number of array elements of 1's and 0's. Even symmetry of nulls about the main beam is an advantage of this technique. However the main beam could suffer some loss in gain and psll increases spatially when number of required nulls increases.

III. Novel Development of Integrated GA/NEC Code.

The cost function for any of the linear or planar antenna array parameters can be obtained numerically using ‘Numerical Electromagnetic code’, NEC that is based on Method of Moments (MoM). NEC is chosen here, as it is probably the most popular and widely available software, however GA could be hybridized with any EM simulator with the same concept similar to [7]. A new code of GA in conjunction with NEC code was developed successfully. A file transfer system is in place to move data between GA and NEC. Special Fortran code subroutines are written to hybridize the two codes and to run the NEC for each of the individuals in the search space. In the developed program, proper treatment was considered for the time delay required to fetch the cost function value from the NEC output file. This integrated GA/NEC code has tremendous advantages to optimize the wire antennas for many antenna parameters such as Gain, F/B, input impedance, beamwidth, far field pattern, and axial ratio. The developed GA/NEC is used in this paper to solve the null steering problem for planar array. The array far field equation for the planar array is given by:

$$F(\theta,\phi) = g(\theta,\phi) \times 4 \sum_{n=1}^{N} \sum_{m=1}^{M} a_{mn} \, cos[(2m-1)\pi d_x \, sin\theta \, sin\phi] \times cos[(2n-1)\pi d_y \, sin\theta \, cos\phi] \qquad (6)$$

where $g(\theta,\phi)$ is far field pattern of the element, M=number of elements in y direction, N=number of elements in the x direction, d_y is the spacing in y direction and d_x is the spacing in x direction. Instead of applying this equation, the far field is calculated numerically using MoM for any type and geometry of array elements.

IV. Numerical Results

Position perturbation, phase only and amplitude control null steering techniques for linear antenna arrays are performed using GA. Optimization is achieved with real and binary parameters. $\lambda/2$ spaced 20 and 40 elements for optimum thinned and Chebyshev linear arrays were considered. These particular arrays are used before in [6], where Chebyshev array was designed to give the same performance of optimum psll thinned array. Figure (1) and figure (2) show the elevation far field pattern of the initial broadside uniform array (solid line) compared with optimum thinned array (dashed line) for 20 and 40 symmetric elements respectively. Optimum amplitude settings of thinned array are designed using GA to give the lowest psll and it is illustrated along with the broadside array case. The resulting relevant psll and main beam angle are –15.55 dB and 28^o for the 20-element case and –18.04 dB and 20^o for the 40-element case. On the other hand, the psll of –13.4 db is the maximum psll that could be obtained for the broadside case even if the number of elements increased to infinity with first nulls at 39^o and 27^o respectively. The optimum thinned array illustrated in these figures will be used as an initial pattern in all of the following nulling techniques.

Figures (3) and (4) show the patterns of phase only control null steering for 20 and 4o linear array elements respectively. Figure (3) illustrates the thinned array and the Chebyshev array relative field pattern where both of them are phase only optimized to give a null at 30^{o}. This position is chosen to reject any interference that could appear in the 1st side lobe next to the main beam, see the 1st psll of dashed line in figure 1. It can be noted that both thinned array and the Chebyshev array give minimum output power, null in the far field patter, at 30^{o}. However, when the thinned array is optimized to give this null the psll is decreased from the reference configuration of –15.55 to –12 dB. On the other hand, psll of the Chebyshev array degrade to -10 dB levels. Also, the results for optimizing the phase shifter settings are successfully obtained for the case of 40 elements to get a null at 25^{o} as shown in figure (4). It is also clear from these figures that the main beam is slightly changed. However, increasing the number of bits assigned for the phase shifter could perturb the main beam dramatically. To avoid this scenario, only some of the least significant bits should be used for the adaptive null steering. In our case, a separate study for 3,4, 5 and 6 least significant bits are converted into continues and real decimal values, which are fractions of 2π. For example, the range from 0.0174 to 0.1567 multiples of 2π is used. Also, it is found that higher value of τ_n within this range gives very deep nulls down to –100dB.

Another program was written for position perturbation technique applied for both thinned array and Chebyshev array. An example to place a null at 35^{o} for 40 elements with -18.04 dB is performed and the results are presented in figure 5. The position at 35^{o} is selected, as it coincides with the position of second psll of the reference pattern (see figure 2 dashed line). A perfect null was obtained for both cases, which indicates that the technique is well implemented. It can be noted that a deeper null is achieved for the thinned array (-100 dB) compared to (-60 dB) for Chebyshev array. As expected placing this null will decrease the psll for both cases. It is found that thinned array is less affected as its psll becomes –13 dB compared to Chebyshev array that is changes to –8 dB. Also wide null (-25 dB) is observed at the range approximately from phi= 30^{o} to 35^{o} thinned array. These previous notes indicate that thinned array is more recommended for position perturbation rather than using the traditional Chebyshev array.

The third null steering technique that is amplitude control is implemented by adding another Fortran subroutine to the GA code. Using this technique, multiple nulls for thinned array using GA were achieved for 20 elements as shown in figure (6). Two nulls were steered at 30^{o} and 50^{o} simultaneously. However, psll deteriorates to -9 dB but it suffers no changes in the main beam shape. Another two nulls at symmetric locations about the main beam are observed at 130^{o} and 150^{o} (see dashed arrows). It should be noted that this property of symmetric nulls appears only for amplitude control technique.

Element Number	Initial Thinned Amplitude	Initial Chebyshev Amplitudes	Position Perturbation ΔS_n	Phase control τ_n	Optimized Amplitude Control a_n	Element Number	Initial Thinned Amplitude	Initial Chebyshev Amplitudes	Position Perturbation ΔS_n	Phase control τ_n	Optimized Amplitude Control a_n
1	1	0.452	0.05987	0.875	1	11	1	0.363	-0.064	0.07813	1
2	1	0.451	-0.02271	0.21875	1	12	1	0.347	-0.03923	0.01563	1
3	1	0.448	0.05161	0.29688	1	13	1	0.329	0.00619	0.26563	1
4	1	0.443	-0.05987	0	1	14	1	0.311	-0.04748	0.9375	1
5	1	0.436	0.01445	0.29688	1	15	0	0.293	0.04335	0.70313	1
6	1	0.427	0.0351	0.59375	1	16	0	0.274	0.05161	0.6875	0
7	1	0.417	-0.05987	0.4375	1	17	1	0.255	0.05574	0.53125	1
8	1	0.406	-0.02271	0.45313	0	18	1	0.235	-0.01858	0.79688	1
9	1	0.393	0.01032	0.28125	1	19	0	0.216	-0.00206	0.57813	1
10	1	0.378	0.01032	0.17188	1	20	1	1.103	0.02684	0.73438	1

Table.1 Computed parameters of 20 elements of the symmetrical 40-element thinned and Chebyshev arrays (initial and optimized for null at 35^{o}) using three different techniques.

Table (1) shows the amplitude setting Chebyshev arrays for 20 elements (half of the array elements) of the symmetrical 40-element that gives psll of –18.04. The second column shows the equivalent thinned amplitude settings. The far field pattern of this array is the initial pattern to be optimized for null at 35^o. Third, fourth and fifth columns show the positions (ΔS_n), phase shift (τ_n) and the amplitudes (a_n) configurations. Figure (7) shows the three null steering techniques where the position of the null is 35^o (the location of the second side lobe of the initial pattern) for 40 elements isotropic point source thinned arrays. Deviation of the 1st null location is observed in the phase control technique, while the most psll deterioration is found in the amplitude control curve. Phase and position weighting techniques have slower convergence rate than amplitude control technique.

Several basic tests were done in the development of GA/NEC code. For example a test is performed for the frequency optimization of wire antenna with matched input impedance constrain. It is found that the first optimum frequency for a length of 1 m to give zero reactance is 143.6 Mhz. this result agrees well with the frequency response obtained using MoM. The problem is then extended to thinning two-dimensional array to steer nulls in a given direction. Results presented here are for a planar array with $\lambda/2$ equally spaced (5×10) elements with lengths of 0.2λ. An array with uniformly excited elements and are all switched on is used here. Fig.8 shows the geometry of an optimized thinned 10×5 elements planar array. The black squares indicate the elements with switched on excitations. Fig.9 shows the E-plane pattern versus that with the target null steered at θ=48 (the place of the 2nd sidelobe in that plane). It is clear that the NEC/GA tool allows us to form the required null with even symmetry about the main beam (see the arrows). This example could be extended to any complex type of elements for planar array.

V. Conclusion

In this paper, fast null fixing techniques using genetic algorithm are used to design adaptive antennas. It is illustrated that thinned array could replace Chebyshev arrays to get the steered nulls with the same pattern requirements. Problems of nulls symmetry about the main beam, slower GA convergence, cost and complexity for null steering designs are main issues. Different null steering techniques using GA were implemented. Numerical comparisons between far field patterns were performed when nulls are steered in the pattern with the different nulling techniques. Main beam distortion and side lobe level degradation are disused for each case. Linear and planar arrays were optimized using either analytically or numerically cost functions. Finally, NEC/GA is developed to be a powerful tool for linear and planar array designs.

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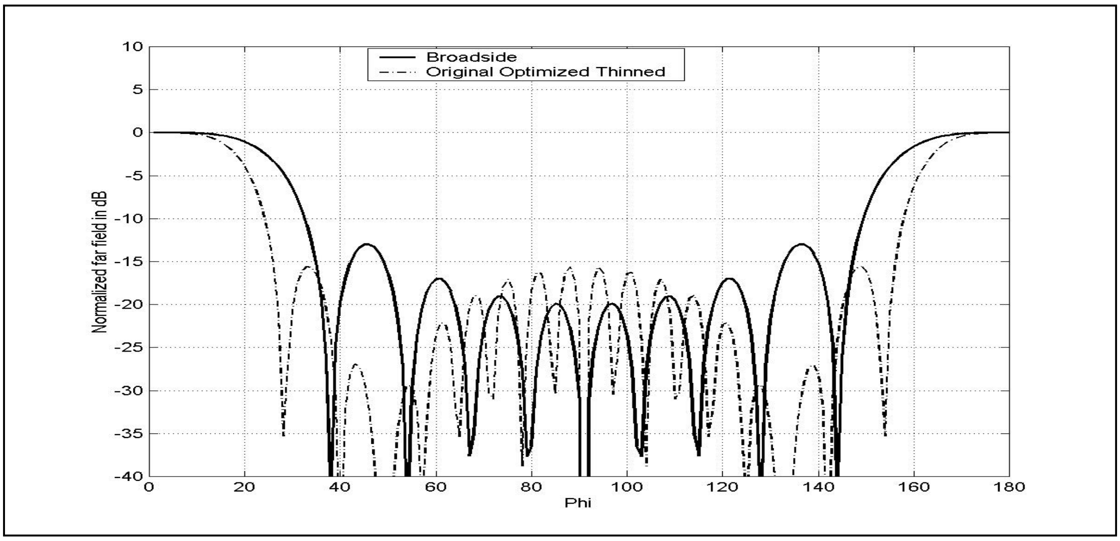

Fig.1. The far field pattern of 20 elements of the broadside array and the original optimized thinned array at -15.55dB.

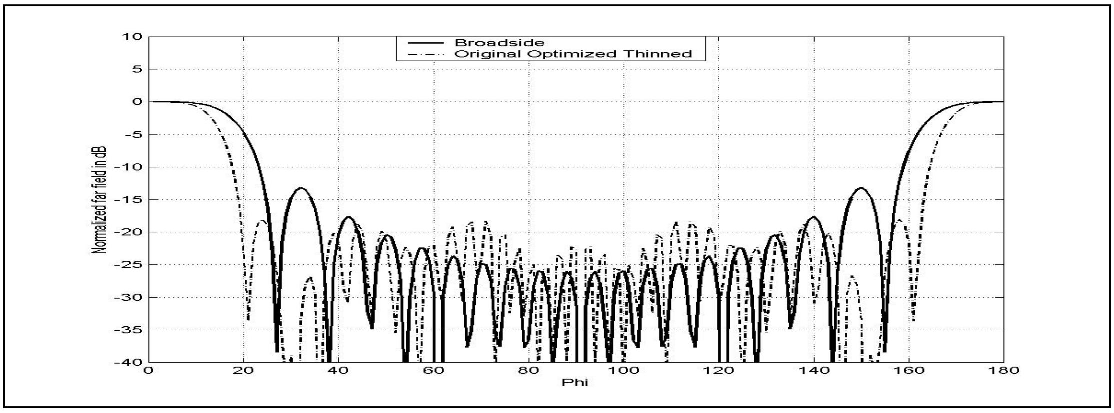

Fig.2. The far field pattern of 40 elements of the broadside array and the original optimized thinned array at -18.04dB.

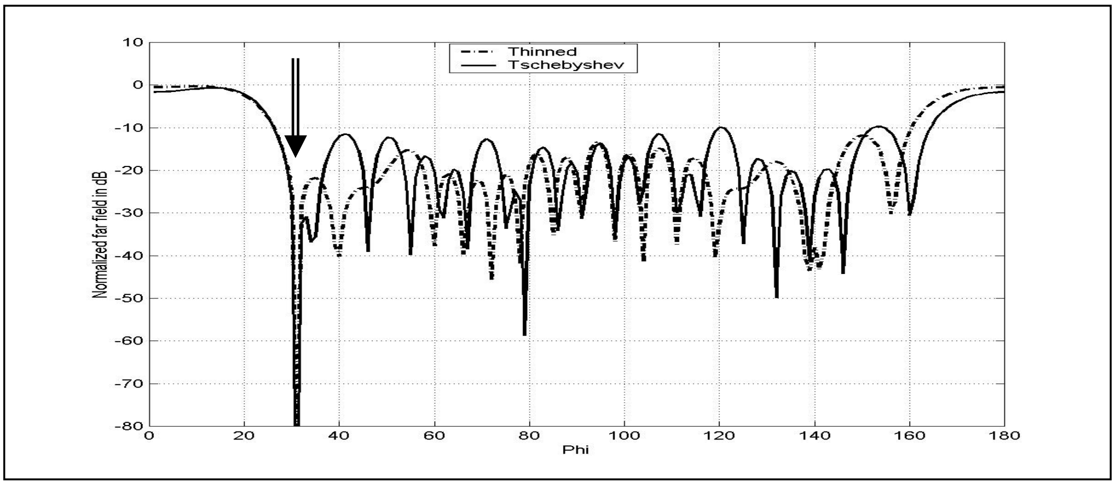

Fig.3. The far field pattern of 20 elements phase only null steering at 30^{o} for thinned array and Chebyshev array

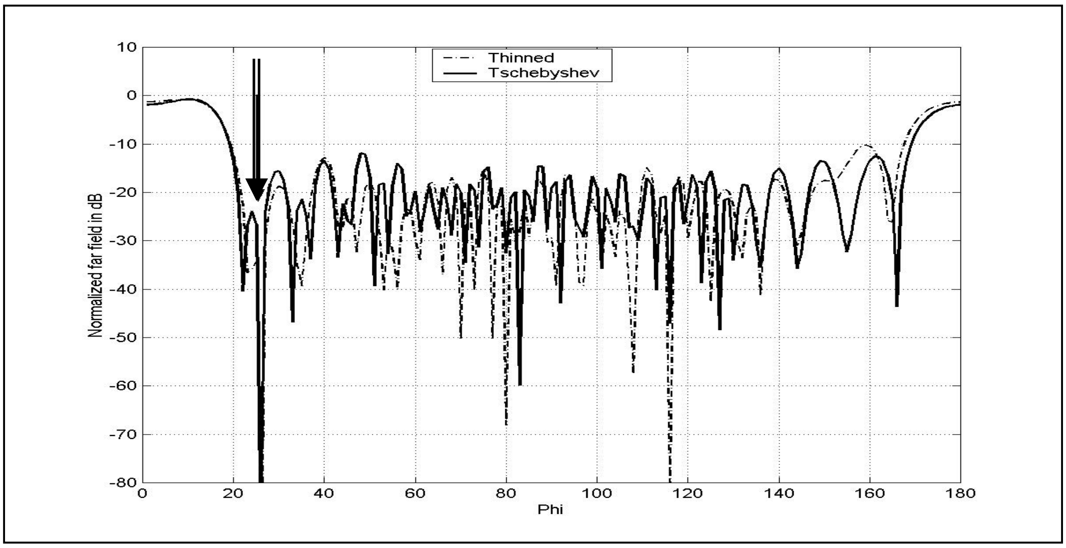

Fig.4. The far field pattern of 40 elements phase only null steering at 25^o for thinned array and Chebyshev array

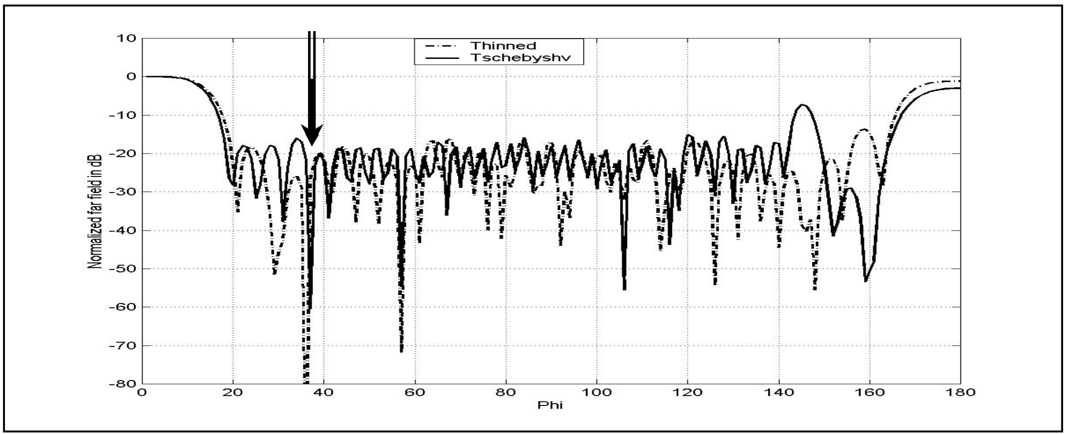

Fig.5. The far field pattern of 40 elements position perturbation null steering at 35^o for thinned array and Chebyshev array

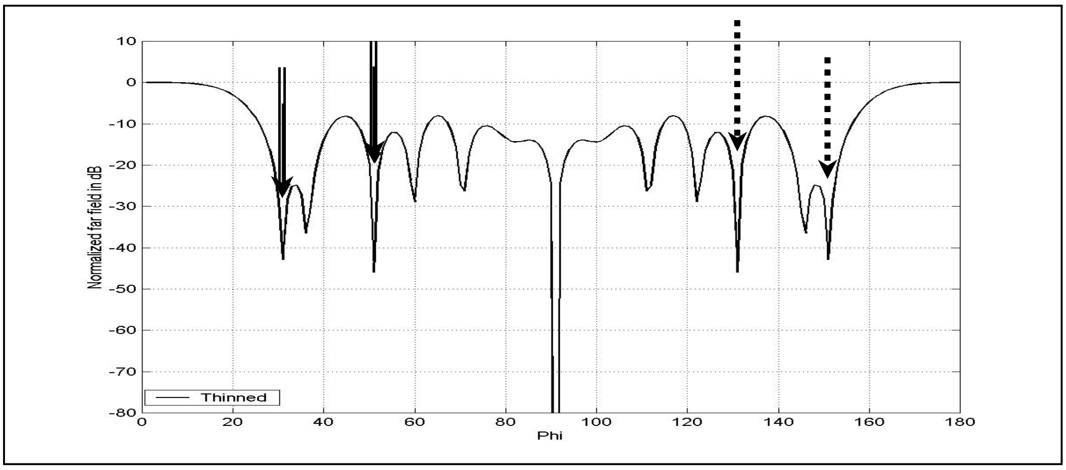

Fig.6. The far field pattern of 20 elements amplitude control multi null at 30^o and 50^o for thinned array

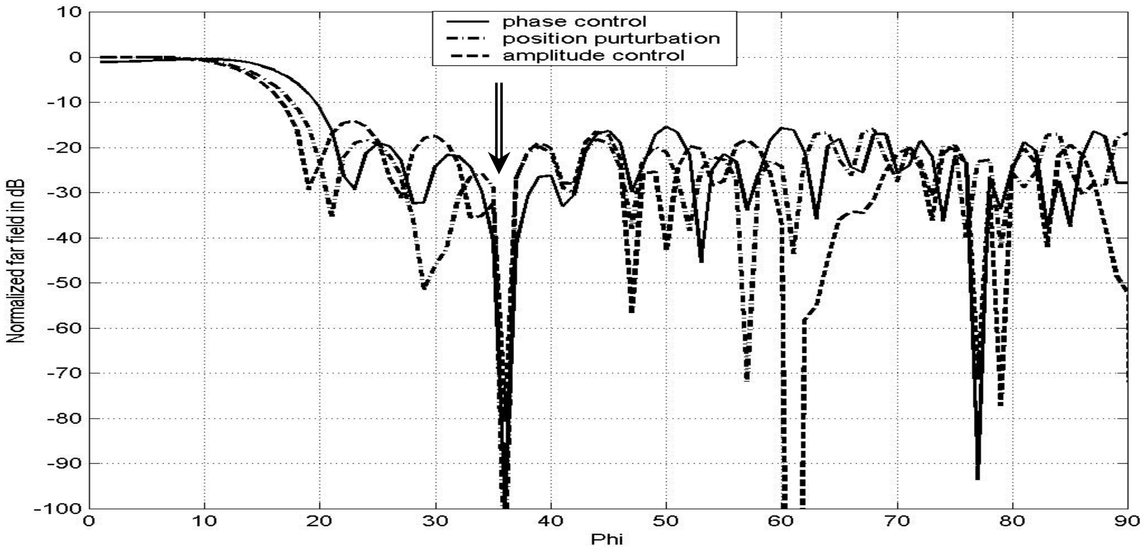

Fig.7. The far field pattern of 40 elements for the three techniques null steering at 35°

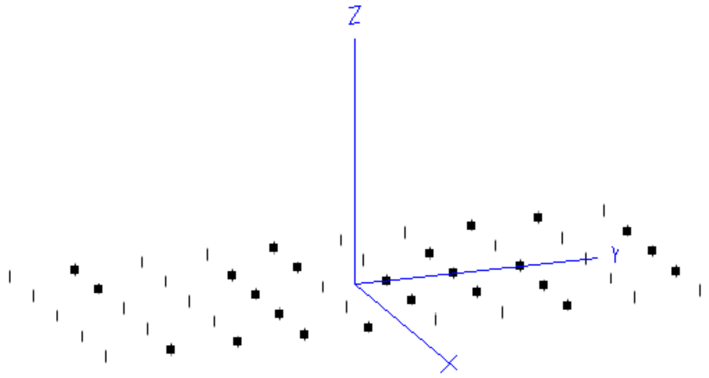

Fig.8 The geometry of an optimized thinned 10×5 elements planar array.
(The black squares indicate elements are switched on)

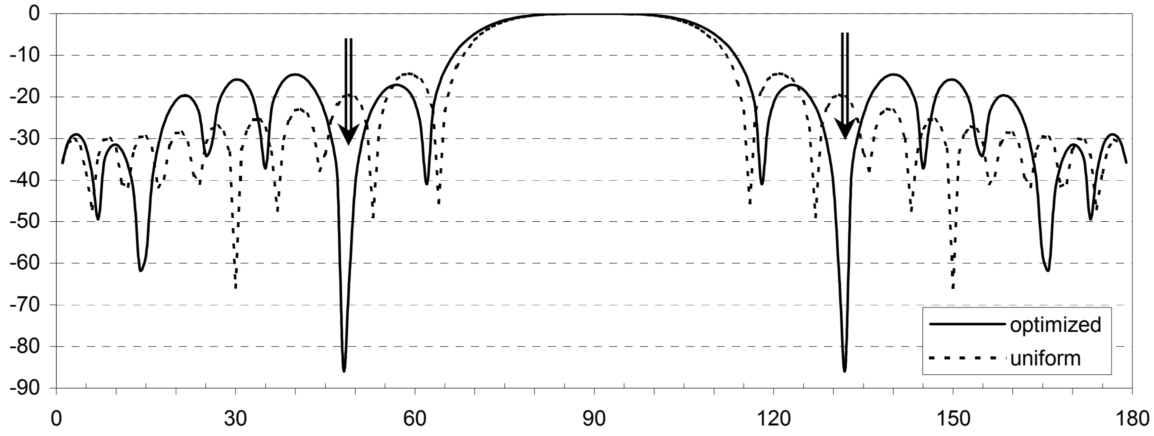

Fig. 9. Far field pattern versus the elevation angle cuts at E-plane.