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Thinning of Linear Antenna Array: A Review

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ABSTRACT: In this paper a review of the technical literature on solving the antenna array thinning problem is carried out. A further work is carried with the brief description of the problem definition and the investigative approach taken up for the study.

Keywords: SLL, HPBW, EAA, Ant Colony Organization (ACO), Particle Swarm Optimization (PSO) and Evolutionary algorithms

I. INTRODUCTION

An EAA consists of a large number of discrete radiator elements placed in a regular grid. In many communication and Radar systems these radiator elements are arranged in a regular linear or planar grid. Characterization of these antenna arrays is normally completed through their Radiation Shapes. Distinctive metrics include Radiation Gain, Side lobe level (SLL), Half Power Beam width (HPBW), Directivity etc.

The process of 'Thinning' involves reducing total number of active elements in the radiator array without producing major decrement in system performance as measured through these metrics. By thinning, repetitions in the array is shattered and henceforth it can also be considered as a subset of non-uniformly spaced array. Factually, immense majority of research labors in this context were concentrated on non-uniformly spaced arrays. The major focus then was to find antenna element positions or inter element spacing using various techniques.

All most of these approaches are deterministic in behavior, because of using measurable and quantifiable knowledge of the array physics to achieve an optimal result. A cost function criteria is developed which is based upon array parameters of interest to exploit information of the deterministic abilities of the array. Typical deterministic optimization algorithms applied to the synthesis problem comprise Newton's Method, Simplex Method, LMS, Conjugate Gradient, as well as many other constrained and unconstrained linear as well as non-linear methods. The inclinations found in the literature related to thinning in antenna arrays are enclosed under the following points

a) Analytical method
b) Numerical algorithm
c) Stochastic Search

Further it is explained as follows:

a) Analytical Method

In linear array with general arbitrarily distributed elements, this far zone pattern was expressed using Jacobi expansion method. The approach used a matrix form solution which requires the management of matrices of the order of no. of elements. It involves expressing the radiation pattern in a series expansion, abbreviating the extension and knowing the solution of the matrix to find the desired spacing. He found that the added grade of liberty created by the random distribution of elements allowed him to achieve the same performance as of an alike space out array with lesser elements. The intricacy of this formulation, has limited its practical applications. It was an empirical approach to select a set of spacing according to a specified law such as logarithmic spacing. Non-monotonically increasing spacing were also investigated and found that they seem to offer promise of a reasonable antenna pattern. It is observed, less no. of elements are required for a desired beam width compared to an equally spaced array. Later on, this tactic provided a better start to the design of unequally spaced arrays. However, it provided less supervision for novel strategies other than those studied earlier. Another method using Poisson's Sum formula and the introduction of a new role to the source function was projected for unequally spaced antenna arrays. This is done by converting the total radiation from the set of antenna from series summation integral and applying the alteration of variables of integration using source function and source number function.

By this, the linear array is substituted by a series of continuous source dispersal, each having a phase variation such that the peak occurs at different angles. Reduction of side lobes and conquest of rough lobes are then endeavored based on one of the conventional techniques. It was found that side lobe level is closely linked with number of elements in the array but weakly connected to the aperture size whereas directivity is linked with aperture size. The Design procedure used for unequally spaced arrays are based on density tapering / space tapering, in which the compactness of equal-amplitude elements is made proportional to the amplitude of the aperture illumination of a conservatively designed array. The key reason for employing density tapering is to accomplish low value of side lobes without the necessity for amplitude reduction. The density tapered technique, when applied to large arrays, appears to give suitable results. In space tapered pattern that is derived from a reference array using an illumination taper having maximum value in the centre of the array and minimum active element spacing will occur at the centre. As soon as the number of elements rises, the minimum spacing decreases; conversely, as the no. of elements decreases, the minimum spacing rises. The minimum acceptable spacing will be determined mainly by the physical size of the element and by the properties of mutual coupling between fundamentals. The corresponding maximum no. of elements will offer the best estimation to the anticipated illumination means; these spacing are later perturbed about their initial value and effects studied. The side lobes can be reduced in height to approximately 2/N times the main lobe level, where N is the number of elements, with main beam width enduring basically the same as for the uniform array.

However, this method seems to be pertinent only to control the side lobes adjacent to the core beam. A second iterative method differs from the first in that it does not start with a priori set of spacing; it builds up the design one element at a time. One of the arrays premeditated by using this method is found to have around 21 elements and is 76 wavelengths long when used as a broadside array. The 3-DB beam width is 0.74 degree, the side lobe level -7.4 db. Such an approach is probably not suitable for applications like radar.

The technique of synthesizing a space tapered linear array involves approximation of a desired current spreading over the aperture. Used for an antenna possessing a continuous aperture, the far-field pattern can be calculated after information of the currents in the aperture. The side lobe structure and beam width of the radiation pattern are controlled by the use of an appropriate illumination function which tapers the aperture current density. In amplitude tapering array, the current sheet of the continuous aperture is approximated by discrete current sources, the elements. The radiance taper is attained by varying the comparative amplitudes of the elements in the array. For arrays, in which the fundamentals are closely spaced (about 0.5 wavelength), there is little difference between the patterns formed by the continuous aperture and by the isolated array aperture. The statistically tapered arrays are useful when the number of fundamentals is large and when it is not applied to employ an amplitude taper to achieve low side lobes.

B) Numerical Methods

In Applied numerical technique approach, the single N dimensional optimization problematic is transformed into a sequence of N one-dimensional optimization difficulties. Consequently instead of examining mN cases for the Brute–Force approach, approximately (N-1) m 2 cases only condition to be observed, where N elements of the array can occupy any one of the m possible locations in the aperture. The design of the complete array is built up from successive designs of partial arrays. In over all this technique will not give an optimum solution for the array, since the inter-element dependence is not completely accounted for in the technique. However, the technique, even with this shortcoming provided the much needed base for the design of one class of antennas. According to the study the grating lobes are suppressed and minimized after incapable sized essentials are laboring in the array. By varying the size of the radiating elements, the positions of the fundamentals will not be periodic and the design among adjacent elements in general will not be equal. The minimax-maxmini algorithm is explained iteratively by the revised simplex technique in linear programming. Also a weighted smallest square technique for optimal thinned antenna arrays. In this work, a weighted least square approach is proposed to find an optimum beam form a Delph-Chebyshev logic. The square of the error between a thinned array pattern and a desired pattern is minimized in such a method that some sections of the array visual range were emphasized than further ones to find an optimum beam pattern. It was revealed that an exponential weighting function is appropriate for achieving a uniform side lobe. Similarly, it was found that the minimum mean square error does not necessarily produce an optimum beam pattern based on convergence characteristics.

Minimax is an optimization process which does not require derivative information; it can be applied to nonlinear difficulties for which analytical results are not easily possible. The process also lends to a condition which has sure-convergence properties. The main impartial in this method is to minimize the maximum error and to maximize the minimum error with reverence to the desired result.

Success in applying the technique to antenna synthesis is based on how well the residues, which represent the error between the authentic and anticipated pattern at the sample points are chosen and then calculated. This method to different types of antenna synthesis difficulties including optimization of Delph-Chebyshev arrays by spacing variation and to find the component conditions in non-uniformly spaced linear arrays with uniform excitation that produce minimized (equal) side lobe levels. The iterative method for minimization is based on successive linear/ approximately linear approximations to nonlinear residuals. Numerous programming approaches have been attempted for minimizing the maximum error α and maximizing the minimum error β as a multi-objective linear programming problem. The simplest method is to minimize α and maximize β on the other hand, subject to the inequality constraints and updating the spacing to each iteration.

In Adaptive goal programming approach, the problem is converted into solving a multi-objective linear programming problem with a fixed goal. Since a fixed goal for the side lobe level is generally not easy to determine, an adaptive procedure of the goal programming is taken under consideration. In this approach, the goals were set for α and β iteratively based on the variance between α and β. When the goals for α and β are g1(k) and g2(k) respectively, the methodology minimized the total error of α, β with respect to their goals, where k is iteration index.

The work already has been carried for conventional minimax algorithm with other approaches for a 51 element array with the array length that of 101-element equal-spaced linear array of half-wavelength element spacing. It is shown that the minimax-algorithm with adaptive goal programming performs best with respect to side lobe. The maximum side lobe level is shown to be -23.5 db. It is found that the side lobe performance is much closer to the Delph-Chebyshev pattern than results obtained with the conventional minimax algorithm. For array steered to 30 degrees from normal, side lobes achieved are about -19 db.

C) Stochastic Search and other Approaches

Search based on stochastic approach is through probability rules, employed in an "oriented random" manner. Such methods uses only information from the objective function, not requiring knowledge of its derivatives or possible discontinuities.

These techniques gained popularity with the recent progress in computer systems, since they require simultaneous working through a large number of solutions of the proposed problem. That is necessary in order to let the method explore properly all regions from the search domain containing the optimal solution. Since these techniques work with probability rules, it is less likely that they will converge to a local minimum.

Some of the significant Stochastic algorithms useful for solving optimization problems are Simulated annealing, Tabu search, Neural networks, Particle Swarm Optimization, Ant Colony Optimization and Evolutionary algorithms. Out of these, Ant Colony Organization (ACO), Particle Swarm Optimization (PSO) and Evolutionary algorithms have been used for solving the antenna array thinning problem. All the three algorithms derive their inspiration from nature and can be classified under NBSA.

In ACO approach they use the array with all elements "on" as the initial value and take advantage of the entire structure in which there is only one nest from which all ants depart. For a 100 element linear array they obtained a Side lobe level (SLL) of -20.52 dB with 20 elements optimally selected to be "off". In case of planar array, the SLL obtained was -25.76 and -25.67 dB in the two orthogonal planes.

By this technique they achieved side lobe levels of -18 dB for a 30 x 30 element planar array with Taylor distribution with a thinning factor of 0.556.

Their simulation study involved various linear arrays from 10 elements to 200 elements and they were able to establish a pareto-front to trade-off between peak SL and antenna elements "turned on". Results obtained from simulation were also needs to be compared with some experimental antenna arrays.

Typically for a 400 element planar array of isotropic sources, a thinning factor of 0.4 having a side lobe level of -22.6 dB could be achieved. An alternate way of obtaining element positions in a non-uniform array is to perturb the element positions within a uniformly spaced array. GA has been used to find the new positions of a linear array with 2N +1 elements by using a side lobe level cost function. The same principle has been extended to scanning radar arrays as well as other applications.

Synthesis of thinned antenna arrays using Real-Coded GA and Hybrid GA i.e., combining both Boolean and real valued variables have been explored for specific cases. When the thinned array has variable amplitude as a parameter for element excitation, SGA with binary coding shall not be adequate. Using a binary coding technique may not only give rise to quantization noise but also shall require time consuming coding / decoding procedures According to the adopted representation, suitable genetic operators needs to be defined in order to attain permissible solutions and possibly enhance the convergence process.

In spite of all the good features of GA in solving a multi-objective problem, a GA-based procedure is fairly slow to "fine tune" the optimal solution after locating a suitable region (called attraction basin) in the solution space. According to [2.44], SGA must be customized for each application in order to give optimal results.

Other techniques such as Iterative Fourier technique, alternating projection technique, Fractal technique, Matrix pencil method have also been attempted for thinning antenna arrays in some form. Work is also proposed for a combined approach including sub array amplitude weights, random sub array and the random displacing rows to reduce the Grating lobes in a thinned phased array.

II. CONCLUSION

Following conclusions are drawn from the literature review conducted on the subject

(i) The topic of thinned array synthesis is a current research topic and many researchers are working in newer areas.

(ii) Synthesis of thinned arrays is a multi-dimensional, multi-objective problem involving nonlinear functions. Though classical analytical methods were being used in earlier years, better results are possible with the advent of fast computing machines and newer techniques.

(iii) Stochastic optimization techniques are better suited for solving this problem. However, these stochastic techniques are fairly slow in converging to optimum results. There is also a need of fine tuning the parameters and adapt the approach for apiece application separately.

(iv) Most of the studies on thinning of antenna arrays are restricted to smaller arrays, involving a maximum of a few hundreds of elements. There appears to be a problem in scaling the approach for handling larger arrays.

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