Multi-Objective Pattern Synthesis Of Large Thinned Antenna Arrays For Low Side-Lobe Levels

Dr.LakshmanPappula,Ms.V.Sahiti, K. Kartheek, B. Venkatesh, M. Siva Prasad

Abstract: This paper shows an approach with more than one objective to synthesis of array antennas which are thin. The focus is on the issue of optimizing peak sidelobe level, first null beam width and number of active elements simultaneously. Such numbers are in contrast with each other. The multi-objective approach provides greater versatility in the layout for the specific application at hand of a thin array. For each set from which different solutions are selected to prove the superiority of the proposed method over previously published methods, a Pareto-optimal front is obtained. The findings also show improvement in aperiodic arrays over the agreed statistical limits. Thus, a three-parameter multi-objective optimization approach is more efficient in controlling the radiation pattern shape compared to two objective optimization parameters..

Index Terms: Thinned antenna arrays, Multi-objective optimisation, Peak side lobe level, First null beam width, active elements, NSGA-II, Pareto front.

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1. INTRODUCTION

Antenna arrays are commonly used in different applications which includes radar, communications with satellites etc. The antenna arrays which have wide area contain a large number of antenna components and due to high cost and more complexity, they are hard to implement. The design of the target radiation pattern is also difficult to control without disrupting the input power which is uniform in nature. In such cases, the aperiodic range obtained by adjusting the antenna component positions provides greater versatility in regulating the rate of the side lobe while preserving a uniform distribution of the amplitude. Through changing of periodic array antennas, an aperiodic antenna array can be optimized. The most desired way is to change the positions of a periodic set of elements to establish aperiodic distance between them. But in practice, changing the places of array elements is difficult and the process becomes complex, especially when the total number of array elements is more. Another solution to aperiodic arrays is by using the thinning concept[1-13]. Thinning of an array is defines as giving power to some array elements and leaving behind some elements without giving power and maintain the radiation pattern as before . Active elements are are given uniform amplitude in thinned arrays, while the elements which are inactive are terminated at matched loads. Thinned arrays have some advantages such as weight. reduction, less cost, less power consumption, and feed network complexity. Therefore, thin arrays can be synthesized to obtain the additional benefit of the low PSLL with the first constant null beam width (FNBW). The challenging part is to synthesize the aperiodic array antennas and in the last 5 decades many thinning methods have been proposed. Finding the optimal thin area from among the vast number of possible solutions for large array synthesis is a complex process that can not be solved through the use of analytical methods. The use of optimization techniques has led to significantly improved solutions. Evolutionary algorithms such as Genetic Algorithm (GA) [5, 6], Simulated Annealing (SA) [7, 8], Particle Swarm Optimisation (PSO) [9], Ant Colony Optimisation (ACO) [10], Boolean Differential Evolution (BDE) [11] and Nested Optimisation Scheme [12] have been successfully applied in thinned array synthesis. All the evolutionary algorithms listed above have shown the ability to search for optimal solutions to one-dimensional optimization problems. But many practical problems with the development of antenna arrays are extremely nonlinear multi-objective issues that require optimization of more than one parameter. For example, strategic removal of antenna elements during the array thinning process suppresses the PSLL. This type of method is good in decreasing the PSLL, but it will have a detrimental effect on the main beam form, as the array's FNBW depends on the aperture size and the antenna elements ' positions. Turning off too many components will increase the radiation pattern of the array FNBW. The above requirements for low PSLL, narrow FNBW and number of active elements are contrasted as arrays with more ON (active) elements have narrow beam widths but they do not give less SLL and vice versa. For one aspect, therefore, the performance can not be significantly improved without degrading the other Sacrificing gain and beam width to get low SLL becomes necessary in many applications. Therefore, to minimize these conflict parameters, it is necessary to determine a set of solutions so that they dont dominate the other solution. The Pareto front is formed by this set of non-dominated solutions[16, 17]. Several optimization techniques with more than one objective[16, 17] have been used in recent years to evaluate the Pareto front for the two conflict parameters I SLL and FNBW[18, 19], (ii) SLL and Null depth[20, 21, 22] (iii) SLL and active component number[9]. An approach with more than one objective using undominated binary genetic algorithm (NSGA)-II[16] is implemented in this communication to minimize simultaneously the three conflict parameters of PSLL, FNBW and the number of active

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components. Many design examples are considered to demonstrate how the multi-objective method is useful in regulating the radiation pattern shape by optimizing these three conflict parameters in large thin arrays.

2 PROBLEM DERIVATION

Consider the uniform linear antenna array with 2N elements as shown in Figure 1. It is assumed that the set is symmetrical and consists only of isotropic components.Consider the uniform linear antenna array with 2N elements as shown in Figure 1. It is assumed that the set is symmetrical and consists only of isotropic components.

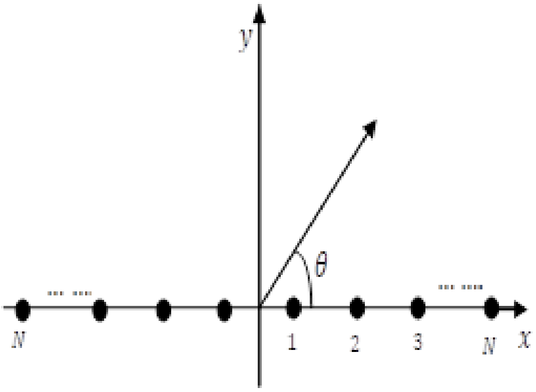


Figure 1. *linear array.*

The array factor (AF) in the azimuth plane [24, 25] is

$$AF(\theta) = 2\sum_{n=1}^{N} I_n \cos[kx_n \cos(\theta) + \varphi_n]$$
(2)

Where θ is the azimuth angle and I_n, φ_n & x_n are the excitation amplitude, phase and position of n^{th} element respectively. The distance between the elements is assumed to be 0.5λ.

Let us assume uniform phase excitation for all elements, i.e.,$\varphi_n = 0$.

$$AF(\theta) = 2\sum_{n=1}^{N} I_n \cos[kx_n \cos(\theta)]$$
(3)

In thinning process, I_n is 1 if the nth element status is ON and I_n is 0 if the status is OFF.

Planar Antenna Array

Consider a planar antenna array of 2n × 2m isotropic elements, which is symmetric about the $x$and y axis as shown in Figure1.

The main goal is to design the optimal thinned array by decreasing parameters which are dependent such as PSLL, FNBW and number of ON elements simultaneously. The corresponding three objective functions are formulated as follows in order to minimize these parameters

i. To minimise the PSLL

$$f_1 = \max\left(20\log\left(\frac{|\mathrm{AF}(\theta)|}{\max\ |\mathrm{AF}(\theta)|}\right)\right)$$

$\theta \in$ sidelobe region

ii. To minimise the FNBW

$$f_2 = 2\theta_{fn},\ \theta_{fn}$$

indicates position of first null. (6)

iii. To minimise the active element number

$$f_3 = 2\sum_{i=1}^{N} x_i$$

3 DESIGN EXAMPLES AND NUMERICAL ILLUSTRATIONS

In this section, with the topology discussed in section 3, multi-objective optimization using binary NSGA-II is used to optimize linear and planar thin antenna arrays. Various design issues are considered and results are presented to optimize conflict parameters for a linear and planar array of 200 elements. NSGA II optimizes over 2000 generations with an initial population of 100 sets. The probability of crossover and the probability of mutation is taken as 0.8 respectively. All computations are conducted on a 4GHz PC with 2 GB of RAM using MATLAB.

3.1 Thinned Linear Array Synthesis:

Consideration is given to a uniformly distributed linear array of 200 elements of isotropic elements with an interspacing component of 0.5π. The measurement time is 28 minutes to scale up to 2,000 generations. With a total of 53 arrays, the optimized arrays were affected. Such final solutions are shown on the Pareto front in Figure 2 of the thin linear range. This approach yields multiple solutions with trade-off between the objective functions of equations 5, 6 and 7, listed below, and listed below, listed below.

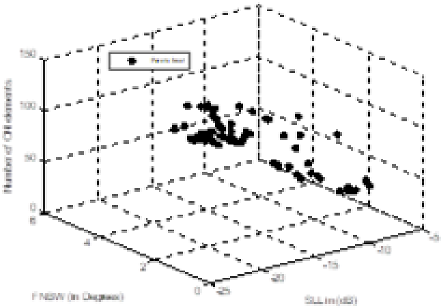


Figure 2. *Pareto front of NSGA-II optimisation*

One of the solutions is chosen for illustration purpose and the corresponding array configuration with element status (on=1 or off=0) is given in Table 1.

The radiation pattern is shown in figure 4. The 74% filled array produces the PSLL of -22.634dB, FNBW of 1.56^0 and the gain [5, 15] of approximately 21.70dB. In comparison the PSLLs obtained in literature using GA and PSO are -22.09dB [5] and -22.40dB [9] respectively. Table 2 gives a comparison of the different results for thinned linear array synthesis.

Table 1. *The elements for the optimised thinned array.*

11111111111111111111111111111111111111111111111111 11111011001100001110101010001101010001001001010010

***Table 2**. Comparative results for linear thinned array synthesis*

	PSLL in dB	FNBW in degrees			Number of ON elements	Gain in dB	
		Original	Optimised	%Increase		Original	Optimised
Present Work	-22.63	1.14	1.56	36.80	148	23.01	21.70
GA [5]	-22.09	1.14	1.46	28.07	154	23.01	21.88
PSO [9]	-22.40	1.14	1.50	31.58	154	23.01	21.88

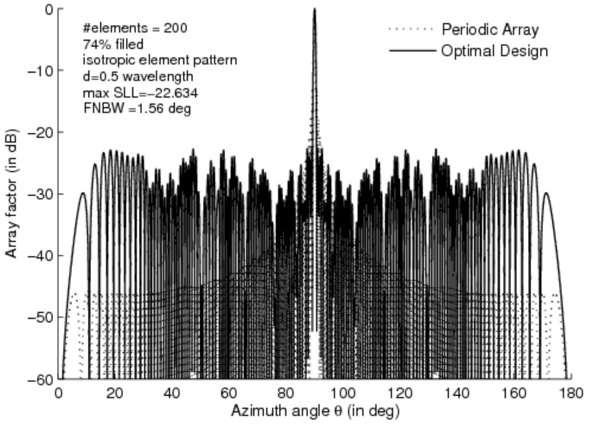


***Figure 3.** (a) Far field radiation pattern of a 200 element thinned array compared with the non optimised array pattern.*

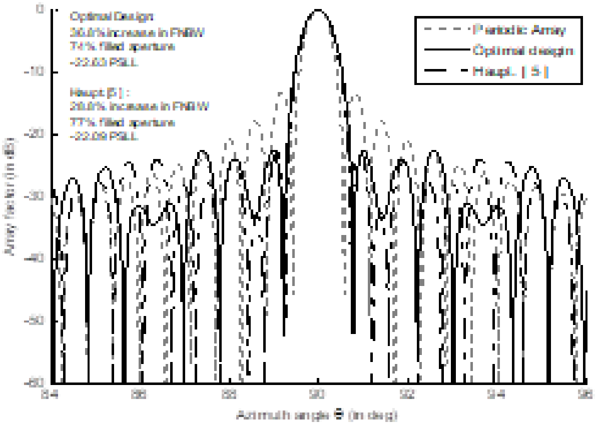


***Figure 3.** (b) Radiation pattern in between azimuth angles of* 84^0 *and* 96^0*.*

3.2 Thinned Planar Array Synthesis:

To extend this approach to planar array synthesis, a broad side 20×10 element with $0.5\lambda_0$ spacing is taken. The array is symmetric about the x and y axis. NSGA-II optimises the population of 100 arrays over 2000 generations. The radiation pattern of the array is computed at 3602 angles in the azimuth region of -90^0 to 90^0. The objective functions are formulated as follows

i. To minimise the normalised PSLL in side lobe region

ii. To minimise the FNBW

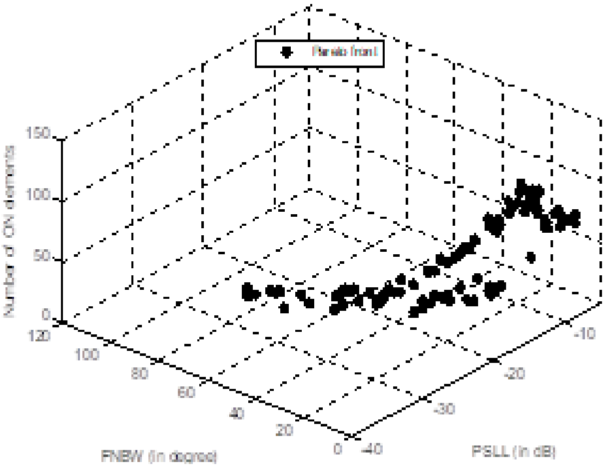
$$f_2 = \max\left(2\theta_{fn} \text{ in } \emptyset = 0^0 , 2\theta_{fn} \text{ in } \emptyset = 90^0\right)$$

■	ON
☐	OFF

Where θ_{fn} indicates position of first null.

iii. To minimise the active element number

$$f_3 = 2\sum_{i=1}^{N} x_i$$



The 35.5% filled aperture (71 elements) produces PSLL of -25.78dB, FNBW of 33.8^0 in $\emptyset = 0^0$ plane and PSLL of -25dB and FNBW of 15.6^0 in $\emptyset = 90^0$ plane. As a comparison, the optimal solution by the genetic algorithm [5] is considered and it produces PSLL of -20.07dB, FNBW of 30^0 in $\emptyset = 0^0$ plane and PSLL of -19.76dB and FNBW of 14.64^0 in $\emptyset = 90^0$ plane. In this case, the array is 54% filled. The optimal PSLL in both planes is 5dB and also the obtained optimised planar array requires 37 less number of elements. At the same time, the FNBW is 12% and 7% wider than the solution achieved using GA [5] in both $\emptyset = 90^0$and $\emptyset = 0^0$planes respectively. Table 7 gives a comparison of the different published results for thinned planar array synthesis and the results demonstrate that three parameter optimisation approach using NSGA-II results in control of radiation pattern with less number of active elements

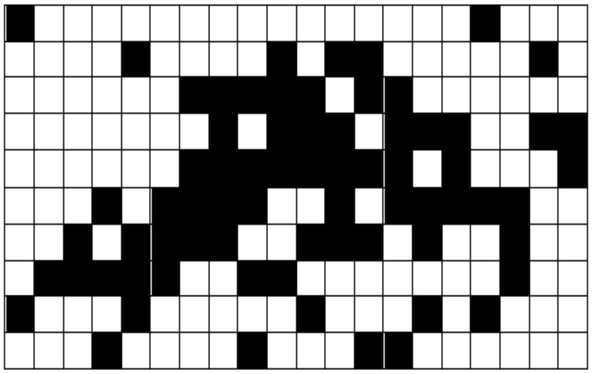


Figure 5. *Layout of the one quadrant of* 20×10 *element optimised thinned planar array*

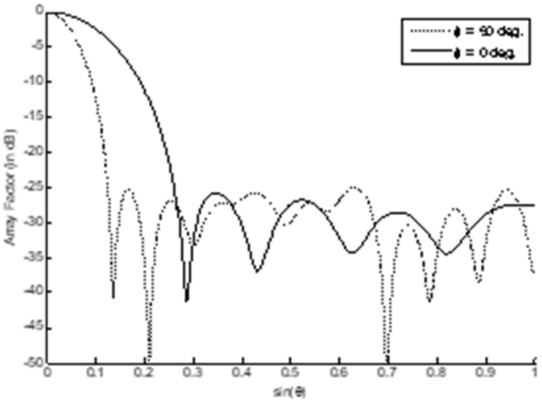


Figure 6. *Far field radiation pattern in* $\emptyset = 0^0$ *and* $\emptyset = 90^0$ *of a* 20×10 *element thinned planar array achieving < -25dB of maximum PSLL*

4 CONCLUSION

A multi-objective approach to the development of thinned arrays using NSGA-II is suggested in this correspondence. This paper revealed many design issues with various configurations of the array. Compared to previous published results, the way is successful in achieving better compromised results in terms of PSLL, FNBW and number of active elements. The optimized designs obtained show that this method provides an effective way of controlling the radiation pattern with a less count of active elements. This three-parameter optimization approach provides more flexibility when it comes to providing the best possible final solutions compared to single and two-objective optimization issues.

REFERENCES

[1] Lo Y. T.: 'A mathematical theory of antenna arrays with randomly spaced elements', IEEE Trans. Antennas Propag., 1964, 12, pp. 257-268

[2] Skolnik M.: 'Statistically designed density-tapered arrays', IEEE Trans. Antennas Propag., 1964, 12, pp. 408-417

[3] Schwartzman L.: 'Element behavior in a thinned array', IEEE Trans. Antennas Propag., 1967, 15, (7), pp. 571-572

[4] Steinberg B. D.: 'Microwave imaging with large antenna arrays'(John Wiley & Sons, 1983)

[5] Haupt R.L.: 'Thinned arrays using genetic algorithms', IEEE Trans. Antennas Propag., 1994, 42, (7), pp. 993–999

[6] Haupt R.L.: 'Interleaved thinned linear arrays', IEEE Trans. Antennas Propag., 2005, 53, (9), pp. 2858-2864

[7] Murino V., Trucco A., Regazzoni.,: Synthesis of unequally spaced arrays by simulated annealing', IEEE Trans. Signal Process., 1996, 44, (1), pp. 119-123

[8] Meijer C. A.: 'Simulated annealing in the design of thinned arrays having low sidelobe levels'. Proc. Symposium on Communications and Signal Processing, Pretoria, South Africa, September 1998, pp. 361-366

[9] Jin N., Rahmat-samii Y.: 'Advances in particle swarmoptimisation for antenna design: real-number, binary,single-objective and multiple objective implementations', IEEE Trans. Antennas Propag., 2007, 55, (3), pp. 556– 567

[10] Quevedo-teruel O., Rajo-iglesias e.: 'Ant colonyoptimisation in thinned array synthesis with minimum sidelobe level', IEEE Antennas Wireless Propag. Lett., 2006, 5, pp. 349– 352

[11] Zhang L., Jiao Y. C., Weng Z. B., Zhang F. S.: 'Design of planar thinned arrays using a boolean differential evolution algorithm', IET Microwaves, Antennas & Propagation, 2010, 4, pp. 2172-2178

[12] Corcoles Juan., Gonzalez Miguel A.: 'Efficient combined array thinning and weighting for pattern synthesis with a nested optimisation scheme', IEEE Trans. Antennas Propag., 2012, 60, (11), pp. 5107-5117

[13] Razavi A., Forooraghi k.: 'Thinned arrays using pattern search algorithms', Progress in Electromagnetic Research, 2008, 78, pp. 61-71

[14] Connor Jeffrey D., Foo Simon Y., Weatherspoon Mark H.: 'Synthesizing Antenna Array Sidelobe Levels and Null Placements using the Cross Entropy Method'. Proc. Industrial Electronics, Orlando, FL , November 2008, pp. 1937 – 1941

[15] Bian Li., Wu Qun.: 'Aperiodic array synthesis using the cross entropy method'. Proc. Microwave and Millimeter Wave Technology, Chengdu, May 2010, pp. 551-554

[16] Deb k., Pratap A., Agarwal S., Meyarivan T.: 'A Fast and Elitist Multiobjective Genetic Algorithm: NSGA-II', IEEE Evolutionary Computation, 2002, 6, pp. 182-197

[17] Petko Joshua S., Werner Douglas H.: 'Pareto Optimisation of Thinned Planar Arrays with Elliptical Mainbeams and Low Sidelobe Levels', IEEE Trans. Antennas Propag., 2011, 59, (5), pp. 1748-1751

[18] Panduro M. A., Covarrubias D. H., Brizuela C. A., Marante F. R.: 'A Multi-Objective Approach in the Linear Antenna Array Design', AEU-International Journal of Electronics and Communications, 2005, 59, (4), pp. 205-212

[19] Khodier M., Christodoulou C.: 'Linear Array Geometry Synthesis with Minimum Sidelobe Level and Null Control Using Particle Swarm Optimisation', IEEE Trans. Antennas Propag., 2005, 53, (8), pp. 2674-2679

[20] Tokan F., Gunes F.: 'Pareto Optimal Synthesis of the Linear Array Geometry for minimum Sidelobe Level and Null Control During Beam Scanning', International Journal of RF and Microwave Computer- aided Engineering, 2010, 20, (5), pp. 557-566