Optimal Synthesis of Elliptical and Hexagonal Antenna Arrays using Meta-heuristic Optimization Algorithms

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Bitan Misra
(Regn. No. 19REC036)

Under the Supervision of
Prof. (Dr.) Gautam Kumar Mahanti
Department of Electronics and Communication Engineering



DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY DURGAPUR
WEST BENGAL – 713209
INDIA

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Abstract

With the advancement in wireless communication, antenna engineers are facing various challenges and requirements. In many practical applications such as high-performance radar systems, WLAN, satellite communications, spacecraft applications, mobile communications, an antenna array should be able to reconfigure different patterns to perform various tasks. Synthesis of antenna arrays can be performed by deterministic and stochastic methods using optimization operations. However, the stochastic approach involves flexibility, the ability to handle significant high-scale problems and other advantages over the deterministic way. In this context, bio-inspired meta-heuristic algorithms, which essentially search for the optimal best result, have been successfully used in the optimization of single and multi-objective problems with many constraints. Meta-heuristic optimization algorithms improve a problem by iteratively trying to ameliorate a candidate solution by considering a given estimated quality. Concerning this, optimization techniques have recently taken center stage in antenna synthesis, where the detailed system design with proven standard performances is performed with accuracy and reliability.

This thesis is focused on the optimal synthesis of various types of elliptical and hexagonal array antennas using meta-heuristic optimization algorithms. Here, in this thesis, the optimal reduction of side lobe level with constraints of a suitable first null beam width of a non-uniform concentric elliptical array antenna of uniformly excited isotropic elements is described. Three meta-heuristic optimization algorithms, namely ant lion optimization, crow search algorithm and moth fly optimization algorithms, are used for the optimal synthesis of the considered array structure in the vertical plane and the horizontal plane. Meta-heuristic optimization algorithms are applied to generate a radiation pattern with low SLL with constrain of suitable FNBW by determining the optimum positions of the array elements in the considered array structure. The t-test is performed at a 1% significance level for all three algorithms separately to find out if the results are correct and relevant to the whole population.

The next study describes the design problem of a thinned multiple concentric elliptical arrays of uniformly excited isotropic antennas. Two simulations are performed here. In simulation 1, the synthesis of the thinned array structure is presented in the vertical plane at a scanning angle of 30° and in simulation 2, the synthesis is performed in the horizontal plane. In both cases, our objective is to minimize side lobe level (SLL)

to the extent possible and at the same time maximize the peak directivity to a level higher than the desired value. Here, all the optimization algorithms are applied to obtain the optimum number of switched on and off elements in every concentric ellipse that will meet the above objective. A comparative analysis of all three algorithms is performed using peak directivity, side lobe level and first null beam width (FNBW) as well as statistical parameters such as mean, standard deviation, best cost function value and run time.

Another synthesis method to reduce the maximum side lobe in the entire azimuth plane and for achieving the desired value of directivity of a concentric elliptical array antenna is addressed in this study. Different simulation-based experiments are performed to obtain the best possible angular positions and the distribution of isotropic antennas across the ellipses by rigorously maintaining non-overlapping constraints. The major benefit of the proposed design is the deprecation of interference in all phi planes.

Again a problem of the synthesis of multiple concentric elliptical arrays of uniformly excited isotropic antennas with an objective to minimize side lobe level (SLL) to the extent possible when the value of the First null beam width (FNBW) is less than the desired value is solved.

Synthesis of a non-uniform elliptical array antenna (EAA) is presented to allow simultaneous minimization of side lobes and maximization of gain by finding the best optimal set of angular positions of the antennas in the array structure. The proposed approach is efficient enough to solve the multi-objective problems at two principle planes of radiation and flexible enough to the efficient implementation of additional design constraints which make this design suitable for practical high-frequency applications as well as long-distance communication.

In the next part of the thesis, the dynamical reconfiguration of a concentric hexagonal antenna array radiation to generate a pencil beam and flat-top beam simultaneously by electronic control in two principle vertical planes is considered Both the beams share a common normalized optimal current excitation amplitude distribution while the optimal sets of phase excitation coefficients are varied radically across the hexagons to generate flat-top beams. Here, a set of simulation-based examples are presented in an integrated way. The proposed optimization technique can produce reconfigurable beam patterns in different azimuth planes successfully with a negligible amount of ripple in the main beam of the flat-top pattern.

The next study is on the placement of multiple nulls as well as minimization of

side lobe level in the radiation pattern using a planar hexagonal antenna array structure in two different vertical planes. The desired null depth is achieved to suppress the interference signal by the position-only control of the uniformly excited isotropic antennas in the array structure. The immediate solution to the mentioned computational problem is reached by various meta-heuristic optimization algorithms. Various examples for diversified scenarios are demonstrated to place multiple deep nulls in the radiation pattern without compromising the pattern constraints and all other radiation pattern characteristics.

The next study aims to introduce an array failure correction in a hexagonal array of isotropic antennas with periodic antenna arrangement. Two meta-heuristic optimization algorithms are used in an iterative way to control the amplitude excitation of the antennas. A fitness model is developed to partially compensate for the side lobe degradation and gain performance degeneration in the power pattern due to element failure. The effectiveness of the meta-heuristic optimization algorithms to design a self-reconfigurable array antenna is verified on different numerical examples.