Synthesis of Planar Array Antenna using Evolutionary Algorithms

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of
Doctor of Philosophy

Kailash Pati Dutta
(Registration No. NITD/PhD/EC/2016/00818)

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



DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY DURGAPUR
WEST BENGAL -713209
INDIA

January, 2022

Abstract

A planar array antenna is one of the most important advancement in the field of wireless communication and electromagnetics. It comprises of multiple antenna elements lying over a common plane and designed in a certain geometrical configuration to obtain enhanced performances and improved spectral efficiency as compared to that produced by a single antenna element. They are not only versatile and reliable but have larger number of control parameters which allow achieving a variety of symmetrical radiation pattern characteristics. The usefulness of the planar array antenna led to their wide range of applications starting from military operation systems to a diverse area including radar, satellite, remote sensing, telemetry, sonar and many other wireless systems. Several research related to the planar antenna array designs have been going on over the past few decades for the improvement of their radiation pattern characteristics.

This thesis is focused in the area of planar array antenna synthesis using the promising evolutionary approach. The novel implementation of some popular evolutionary algorithms and meta-heuristics for the synthesis purpose of the planar array antennas with concentric circular and rectangular array geometries are discussed in details in this research.

Multiple concentric circular antenna arrays hold a common centre and are advantageous over other array geometries in terms of all azimuthal scan capability, frequency invariant features, and lack of edge elements making them negligible sensitive to mutual coupling. They have remarkable spectral competence with great features and hence have gained demanding attention especially in the utility of scanning, direction finding, satellite, aviation and advanced wireless communications.

In this thesis, firstly, the uniformly excited multiple concentric ring antenna arrays are investigated to achieve simultaneous optimization of sidelobe levels and directivity. Various constraints such as inter-element spacing and/or circular ring radii are kept into consideration to achieve the optimal results. Secondly, this work concentrates on generation of desired radiation pattern with simultaneous optimization of the sidelobe levels and directivity for the thinned concentric circular ring array antennas. For solving the thinning problem, some of the design variables that have been considered here are inter ring radii and the number of switched 'on' and switched 'off'

array elements. In both the cases, the fitness function is so formulated that at one hand, it minimises the sidelobe levels where as at other hand, it enhances the peak directivity while satisfying the constraints. The necessary comparison is shown among the various evolutionary algorithms used in both the works in terms of their radiation beam characteristics and statistical performance in order to showcase their effectiveness. The optimal results obtained in both these works are found to be better than those available in the literature.

Synthesis of the non-uniform planar array antenna with rectangular geometry having smaller number of array elements for a desired radiation beam pattern is yet another challenging and complicated design problem. Though there are two common types of non-uniform planar array antennas namely thinned array and sparse array, the later can achieve highly reduced SLL placing the antennas strategically on the array aperture since it has more degree of freedom as compared to thinned antenna arrays. As a result, sparse array may offer superior performance for array synthesis. They are lighter in weight and lesser in cost with smaller number of design variables which reduce the unnecessary complexities. This makes them suitable in applications like satellite, radar, as well as acoustic communication in aviation, defence etc.

The later part of this investigation focuses on the synthesis of a symmetric planar sparse array with rectangular geometry. The aim of this work is to obtain the maximum suppressed value of the side lobe level (SLL) in the radiation pattern in two vertical planes as well as in all vertical planes. The optimized positions of the omni-directional radiating antennas in the array are obtained having multiple optimization constraints such as total number of antennas in the array, aperture area and minimum inter-element spacing. The proposed approach suitably evaluates for best feasible solution satisfying the constraints. It decreases the design complexity and reduces the computational efforts as well. Last, but not the least, synthesis of the sparse planar array is carried out to place multiple small and wide nulls at the desired angles with minimization of side lobe level using a non-linear mathematical approach with constraints like as inter-element distance, limited number of elements, and small aperture. In the proposed work, the null placement does not require variation in the current amplitude or phase excitation. Only the positions of the elements are varied to avoid small or wide band signal interferences.

In this thesis, the evolutionary algorithms that are used are crow search algorithm, moth flame optimization algorithm, symbiotic organisms search algorithm,

quantum particle swarm optimization, and teaching learning based optimization algorithm. Essential care is taken into account to select the tuning parameters of the algorithms wherever applicable along with the basic design parameters like include run number, iteration number and population size. To evade the overlapping of the array elements in the antenna and to minimise the effects of mutual coupling to a negligible value, minimum spacing constraints between the adjacent elements is taken due care in all the cases. This thesis includes the details of the performance features of the meta-heuristics and evolutionary algorithms in terms of their statistical values and computation time. All the simulations were performed in MATLAB 2015b version using a PC/Laptop having Intel core i5 duo 7th generation processor with 8 GB DDR4 RAM.

The simulation results presented in this thesis demonstrate that the proposed planar arrays are superior in performance than the prevailing works in the literature. The comparative studies with the best results present in the literature represent the successful application and effectiveness of the diverse methods and different evolutionary algorithms in the design of planar array antenna. Taken together, these approaches have the potential for efficiently improving the performance characteristics for planar arrays generating significant results. In short, this thesis briefly discusses the impact of these evolutionary algorithms in the synthesis procedure of the planar array antennas.

This thesis is composed in 6 chapters. The first chapter gives the introduction; the second chapter gives the basic concepts of the antenna arrays as pre-requisites. Chapter 3 presents the details about the evolutionary algorithms that are used in this investigation. The chapter 4 deals with the synthesis of concentric circular array antenna. The synthesis of sparse planar array antenna is dealt in Chapter 5. Chapter 6 gives the conclusion and future works followed by references.