Chapter 2

Literature Survey

2.1. Introduction

Modern communication technologies hinges upon antennas, have grown at its fastest pace in the last several decades. The potential of myriad application of antenna attracts researchers to invent and improve the present design technology to achieve better performance characteristics. In the previous chapter an overview is presented of this dissertation which comprises of discussion on very modern phased array antenna and its synthesis through optimization techniques. In this chapter, a literature appraisal of this dissertation is presented that will provide a comprehensive review of the current and historical fields of interest in the area of synthesis of phased array antenna with an emphasis towards application of optimization techniques.

2.2. Background

The origins of antenna as well as wireless communication development inception on 1865 with the seminal paper on electromagnetic field theory of James Clerk Maxwell’s (1831-1879) [1-3] where it was explained that electrical and magnetic fields could propagate as waves through space moving at the speed of light. The German physicist Heinrich Hertz’s (1857-1894) proved and established through experiment in 1887 that Hertzian wave, later named as radio waves could be generated experimentally and were reflected by metallic objects[4]. The price less gift from him in the field of radio communication are half wave dipole, end loaded dipole and parabolic reflector antennas. Sir Jagadish Chandra Bose the great scientist from India, had invented a complete communication setup of transmitter and receiver system, working with 60 MHz using cylindrical horn antennas which was first two way wireless communication in true sense[5]. Sir Oliver Lodge first provided the concept of monopole antenna along with his great invention bow-tie and bi-conical antennas[6]. The first experimental application of electromagnetic radiation conducted by Christian Hulsmeyer used to build a simple device for detecting and avoiding ships collision at fog [7]. It was the first RADAR like commercial system to detect an object using radio wave technology. Later on Guglielmo Marconi (1874-1937), successfully conducted a set of experiments on radio wave communication system for long distance communication applied a fan and monopole
antennas for travelling larger distance [8]. This invention sparked a wider interest in worldwide communication and development in radar system. There was huge development in wireless communication and antenna design observed during world war. Design of an antenna array was first introduced in military applications in the 1940s instead of a large antenna was found advantageous. The gain of certain directional antennas at far field, can be increased by increase in distance between array elements though elements are not strictly phased, was shown experimentally[9]. The first mathematical model was suggested for linear arrays to control its directive properties by complex algebraic polynomial method that represents the radiation direction in the space[10]. An important relation between maximum beamwidth and its respective side lobe level of a radiation pattern of a linear symmetric broadside arrays was established [11]. It was shown with examples that when all the elements are excited with same phase but a current distribution whose magnitudes are the coefficients of Tchebyscheff polynomial, an equal valued sidedelobe are produced for a fixed beamwidth. A numerical computation technique evolved to calculate the phase and magnitude of the field for approximating a polar diagram of the specified aperture plane[12]. Dolph’s paper could not mentioned about the directivity of the array, a mathematical analysis was done for approximating directivity when the elements spacing more than or less than half wavelength[13]. The broadside power gain of uniformly illuminated array will not be maximum except the ideal isotropic point sources. An approximation method is suggested for the current distribution of practical array elements which can produce as closely to the desired radiation pattern[14]. Practical approaches of application of electromagnetics from various theories and formulations are listed and described for engineers and users[15-17]. Aperiodic array concept incubated by introducing a new array arrangement by placing the array elements with arbitrary distribution and also a matrix relation found between the array and far field radiation pattern[18]. Steerable uniform linear array produces grating lobes along with other minor lobes. To control grating lobes and to reduce side lobe level unequally spaced broad band array considered also cosine term of the array factor was varied precisely control grating lobes[19-21]. Antenna is the most important radar communication. A detail of radar communication along with associated antenna technology is thoroughly illustrated[22]. Previously linear arrays were analyzed most of the time, here the relation between directivity and beamwidth is discussed for uniform planar array. Another new analysis of array pattern described that application of Fourier series in array pattern formation[23]. A novel concept in array design, thinned array, had been introduced that becomes very interesting area for the researchers. Here a probability density function of
amplitude taper is considered to removing or switching off some elements from a fully populated planar array and the density of the elements are tapered from the centre towards the edge. Array thinning particularly for large array provides better side lobe level control and cost effective with respect to fully populated array [24]. Method of minimizing a function is suggested by comparing the function values from vertices of a general simplex and replacing the highest value with another point, ultimately reaching to the minimum value among the neighbours[25]. Maxwell’s equation reappraised with a set of finite difference equations which can be applicable boundary condition of perfectly conducting body. This new theory improve antenna design with different materials and analyze their behaviour at different medias[26]. Adaptive array would to produce main beam towards the received signal direction and placing interference to any other direction had been suggested by automatically adjusted variable weight of the signal processor using least mean square method signal processing[27]. Dolph-Tchebysceff array could not mention about directivity of the array. This practical limitation overcome by suggesting a mathematical procedure to approximate the relation between directivity and beamwidth of a large scanning Tchebyscheff array[28]. A simple method for shaped beam pattern is illustrated using Gaussian quadrature method from non-uniformly spaced linear arrays, which require less elements and lower variation of excitation current [29]. Array pattern synthesis is done by minimizing the Fourier coefficients of actual and desired array pattern. This method is suitable for practical array design problems whether array size is specified or not, as highest order Fourier coefficients are the priori [30]. When the elements are excited with binomial distribution then the radiation pattern shows some special features like, a broad beam without side lobe will appear if the array spacing is less than half wavelength[31]. Holland first described a method integrating sampling, learning, control with computational mathematics processes for optimization inspired by biological adaptation. This method becomes very famous by the name genetic algorithm, a global optimization technique in true sense, can be applicable to solving problems in any field[32]. A derivation method is recommended for optimization of signal to noise ratio of an array antenna and also calculated optimum element weight of an adaptive array[33]. Complicated current distribution of Dolph-Tchebyscheff array is calculated through two different algorithms. Nested product (NP) algorithm which defines a finite polynomial as a nested sequence of multiplication and addition, it is a ready computation method, also work good for large arrays. Another new algorithm suggested a faster and lower cost array system equations in a matrix form[34-35]. Detail development is presented in a theoretical review about phased array, finite, infinite and very large arrays. Generalized
formulation including mutual coupling effects in presence of ground screen with examples using conformal array, printed circuit or wide angle scanning array are also described[36]. In cognitive radio network when primary and secondary users coexist, then power allocation between them a becomes critical. To solve this key aspect an approach is considered applying game theory and simulated annealing optimization algorithm in a distributive manner[37]. In practical array antenna, performance depends upon interference suppression mainly mutual coupling effect between elements[38]. Adaptive array design is proposed by controlling interference using least square and least mean square algorithm. Linear programming based polynomial-time algorithm is suggested and can be use for optimization of array synthesis[39]. A comprehensive discussion is provided about the focused aperture amplitude tapering and its effect on fore lobes, back lobes, side lobes and gain of the array antenna is compared with respect to Taylor array tapering and uniform excitation[40]. Side lobe level of array antenna also depends on elements excitation phases. The observation in various cases of linear or planar array noticed that logarithmic function of array size can determine the optimum side lobe level which has greater efficiency than amplitude tapering. As the numerical computation is impractical for large array to find individual phase for optimum side lobe, an algorithm is suggested to calculate phase distribution of the array for optimum side lobe level[41]. Nonlinear amplitude optimization is a complicated process for array excitation, a new concept showed that non-uniform element spacing either by regular thinning or FIR filter design concept can produce controlled side lobe level for uniformly excited array[42]. A detail analysis of Woodward-Lawson method of array design is presented and this method is criticised for its formation technique that beam pattern is governed by progressive phase shift between the elements and nulls perturbation. This analytical method is simple but practical scope of use is limited, another numerical computation method, Orchard-Elliot-Stemmer, is suggested for practical beam shaping array synthesis [43-44]. Array synthesis is done for pencil beam array and super directive array with adjusting side lobe level by null placing radiation pattern through +zero placement on array polynomial is described with detail evaluation[45]. Computer based array synthesis algorithm with detail pattern analysis for basic arrays such as linear array, planar array, phased array and conformal arrays are outlined with various array parameter controlling features[46]. Woodward-Lawson sampling process, only suitable for line source continuous aperture. A practical application of array synthesis is suggested for finite linear array with this sampling method with arbitrary excitation which can reconstruct the far field array factor pattern from the sampled value[47]. Detail description and suggestion for parameter control
evolutionary algorithms is recommended[48]. Array synthesis for phased array and adaptive arrays done by null steering towards interference direction and reaching to the asking null depth, using genetic algorithm is illustrated[49]. Traditional array tapering methods and optimization methods are found not suitable for thinning of large array antenna to achieve low side lobe level. Global optimization technique, genetic algorithm is applied for thinning or switching off some elements from the fully populated array so side lobe level can be going down[50]. Two methods of optimization of thinned array are proposed for 1D and 2D arrays. First method suggest linear programming based optimization algorithm for side lobe level reduction by optimizing weight of each elements and the second method optimizes both layout and weight of the array[51]. Recombination or crossover of real coded GA is mainly intuition based, that may produce children unnecessary close to the parent chromosome. A new concept is provided for crossover based on search characteristic of binary single point crossover. This concept established with some examples which shows better performance than previous RGA continuous search space[52]. An optimization technique is presented using GA reduce side lobe level by optimizing quantized amplitude and phase tapering, in another approach only quantized phase tapering is done instead of continuous phase space[53-54]. A new concept of simple natural optimization, particle swarm optimization, without evolution operator is introduced[55]. Another new optimization technique, simulated annealing, is applied to synthesis of array resulting lower side lobes through optimizing element position and weight coefficients[56]. It was shown steering vectors linearly depending on contribution of the multiple sensors electromagnetic vectors, also upper and lower bound determined for the array[57]. It becomes ambiguous when several signal reaching to the array and which is being responded. A method has been proposed which determines similarity between array response and direction arrivals, and noticed array geometry associated with highest lower bound provide best performance, thus can be suitable for thinned array[58]. The practical application of electromagnetic theory has to consider various real world constraints which cannot mitigate directly. A new approach is taken into consideration for less interference communication, through optimization using genetic algorithm which leads to result of global solution[59]. Computation of electromagnetic field related operation and their processing is given in detail with computer application in [60]. Array synthesis process with constraints of pattern shape in narrow and broad frequency bandwidth is expressed as a convex optimization problem and solved numerically by interior-point-methods[61]. A simple and flexible GA is described without binary coding and crossover concept using real point decimal crossover where the inputs are
complex valued chromosomes. This GA is applied to side lobe reduction of radiation pattern and found very suitable for determining complex phase and amplitude of the excitation through phase shifter[62]. Electromagnetic computational methods are explained, with an excellent coverage on both integral- and differential-equation based techniques exclusively explained systematically[63]. A history with detail description of evolution to application of electromagnetic field in radio communication is narrated[64]. In array synthesis, it is always neglected array geometry, though the optimal geometry corresponds to the lowest Cramer-Rao bound that produces low ambiguity at low SNR. Searching for optimal array geometry GA and simulated annealing algorithm are suggested for optimization[65]. Problems of designing low peak side lobe level for thinned linear and planar array are stated. Designing of array done by optimization method using simulated annealing, performed well as compared to optimization by GA[66]. Classical array synthesis determines the current distribution of equally spaced array to get the desired far field radiation pattern. It was shown variable spacing between elements, that determines by simple inversion algorithm, would be advantageous as it provides better performance of equal spacing array with reduced array size, weight and less number of elements[67]. A new concept is introduced for design integrated antenna by applying optimization using a combination of genetic algorithm and method of moment technique (GA/MoM) with direct z-matrix manipulation. This technique reduces optimization time in practical cases[68]. Array synthesis by classical optimization very often got stuck into local minima problem. Two methods of GA are suggested to perform array synthesis for a specified beam shaping null directions[69]. All previous applications of GA in array synthesis only followed traditional GA method by selecting a predefined population size and mutation rate. Here a novel idea inserted about these two parameters of GA by selecting optimum population size and mutation rate for a simple real GA which will reduce runtime of the optimization may be use in dynamic environment for real time operation[70]. Modern cellular communication uses extensively cell sectorization, using sector antenna. Inefficient sector antenna produces inter-sector interference with high ripple within the sector. A new technique for sector beam synthesis is suggested using phased array antenna and optimization, which will minimize inter sector interference, increase in beam efficiency and lowering the peak to peak ripple[71]. A further development of particle swarm optimization is discussed and modified various parameters such as constriction factors, inertia weight and tracking dynamic systems with probable application are listed [72]. This book described and listed all description of antenna from its inception to various application antenna models [73]. GA and PSO are successfully used in various
electromagnetic optimization problems. An attempt is taken to hybridized these two algorithm for faster optimization for designing a profiled corrugated horn antenna[74]. Scanning of thinned phased array is limited due appearance of grating lobe when the inter element spacing increased more than half wavelength. A method of optimization is suggested using GA to design a thinned array antenna which will restrict appearance of grating lobes during scanning[75]. Plane wave is important for antenna measurement under test. It is proposed to create a plane wave from line sources using GA for optimizing location and weighting of the array to approximate the desired aperture for test[76]. This book focusing on various antenna design by numerical computation method and computer simulations along with detail description of antenna theory[77]. PSO is simple, stochastic and very robust computational technique. Considering these advantageous features, the algorithm can be used in any electromagnetic optimization problem are described and listed with various application, also an attempt is taken to modify the boundary condition[78]. Phased array antenna is optimized for low side lobe level by amplitude only, phase only and complex tapering method optimization using GA and PSO separately. Afterward the simulation results are compared listed all pro cons of these two methods according to their performances[79]. An approach is presented to reduce peak side lobe level through massive thinning of a large array. Thinning is done by optimization using a combination of GA and a combinatorial technique, difference set method[80]. Application of GA in practical field precisely for practicing scientist, engineer and whoever interested in learning of GA, this book might be phenomenal. Moreover various coding and example is demonstrated through MATLAB and Fortran software, thus very useful for computer programming[81]. The classic book described in detail RF and microwave engineering, which includes fundamental electrical engineering in microwave application, analysis of microwave network with its associated circuits and devices, wireless communication system and radiation hazards, also mentioned modern active noise control RFCMOS devices[82]. An analytical mathematical based computation technique is provided to array synthesis of linear, rectangular and cylindrical array geometry for a fixed current distribution with adjustable element spacing. This proposed method can save CPU time and memory space of computer with respect to any nonlinear optimization technique as this method does not involve any iteration thus can be suggested for real time operation[83]. PSO is a global optimizing tool used for an array synthesis purpose of pattern optimization of hexagon antenna array is illustrated with simulated results[84]. Phased array antenna mainly used in practice at radar communication which required very precise scanning and point to point connection through very narrow
beam. A detailed guideline with example are presented particularly focusing GPS navigation system for radar[85]. The backbone of wireless communication is its circuitry, mainly antenna. All the details of antenna theory and various antenna design are listed in this book very elaborately[86]. Linear array synthesis is performed to achieve minimum side lobe level and controlling nulls in the radiation pattern using PSO algorithm. From array geometry the optimization problem formulation determined then PSO algorithm is applied to side lobe reduction and null placement, later the simulation result is compared with the result from quadratic programming method[87]. A novel evolutionary optimization technique, combination of PSO and finite difference time domain (FDTD), is suggested for multiband and wide band patch antenna design. Antenna geometric parameter optimized by PSO and in parallel, fitness function evaluated by FDTD methods to reduce computation time. This concept is demonstrated with two examples and simulation results exhibit the prospect of PSO/FDTD algorithm for practical patch antenna design [88]. The difficult array pattern synthesis in practice is sector beam pattern generation. Two approaches of sector beam pattern synthesis is suggested, first the array synthesis using recursive least square (RLS) method and the second one is amplitude only optimization using GA[89]. Phased array antenna is suitable choice for modern communication as various antenna properties can be directly varied by its associated electronic hardware. Thus the detail of phased array should be in knowledge of any communication practicing individual. All the useful information and detail theory of phased are described and listed in [90]. An array synthesis method for planar array is presented for side lobe level reduction and null placing on the radiation pattern, using PSO optimization method[91]. Unequally spaced large array synthesis is hardly possible by any computational method. Gradient descent optimization method is generally converged to local minima, a new global optimization technique ant colony optimization (ACO) is proposed to design thinned linear and planar array using side lobe level as the parameter[92].

A tutorial survey presented about application of convex optimization in the design and analysis of communication systems and signal processing algorithms. Various examples are shown by conic optimization and second order cone programming for communication problems [93]. It is known that array antenna performance significantly degrades due to mutual coupling effect among the elements. A remedy is suggested to reduce this effect by finding an accurate matrix model of mutual coupling. Later using this model for an UCA antenna simulation is done, made a real model using dipole antenna , and the real measured results are validated with the simulated one[94]. A common optimization function is proposed which can generate narrow beam pattern and sector beam pattern as per the required
optimization. Floating point real coded GA is applied for optimization, two views are followed to generate the desired wave pattern, one is amplitude only method another one optimize both complex phase and amplitude[95]. Here a new analytical method is suggested for phase controlled array synthesis following Schekunoff’s unit circle method. The array factor is represented as a polynomial which is the product of sub polynomials that represents nulls, and their roots are lying on the unit circle[96]. Interference suppression is addressed through optimum array geometry. Optimization problem derived from array antenna is subjected to an interference environment, and to solve this problem optimization is performed using simulated annealing optimization algorithm[97]. A review is presented on application of evolutionary programming(EP) on antenna, microwave, RF circuit and other electromagnetic optimization problems. Here, EP considers mutation only or self adaptive approach during evolution, so it can be easily designed and less time consuming. Lastly, a hybrid algorithm , EP-GA is suggested for electromagnetic optimization[98].

Antenna design parameters includes continuous variables, such as size, while some finite valued variables like permittivity. To solve such mixed integer problem, mixed integer GA which can work with real and binary values in same chromosome, is suggested to design a phase taper low side lobe level circularly polarized patch antenna and thinned array[99]. Linear array synthesis based on a novel interpolation scheme is suggested. This scheme reduces optimization variables also add large degree of freedom to design array. Optimization purpose GA is applied which also converges very fast due to adopted interpolation strategy, and results radiation pattern of very narrow bandwidth and reduced side lobe level[100]. Minimum side lobe is determined for an arbitrary linear array of a particular beamwidth at any scanning direction and any type of element, by two steps optimization. At first optimum weights for each element are determined for minimum side lobe level then array position are determined by PSO algorithm[101]. Array synthesis is performed on uniformly spaced array geometry by optimization using GA to achieve a desired beam pattern with further reduction in side lobe level. This provides design flexibility of smart antenna beam forming, presented through some examples[102]. Reconfigurable array antenna design is proposed to generate multiple radiation patterns, such as pencil beam or flat top beam by element position perturbation using generalised generation gap steady state GA(G3-GA) optimization technique. Here amplitude distribution is same, but array synthesis is performed by inducing a little perturbation in element position or by varying excitation phase. It is shown that proposed method produce better result with respect to phase only optimization method and during scanning the side lobe level can be maintained without distorting the main beam[103].
Modified PSO algorithm is applied to thinning multiple concentric circular ring arrays with large number of elements to reduce side lobe level. Two cases are studied, first uniform element spacing with unity amplitude excitation and in another case an optimum inter element spacing array considered for optimization, lastly the effectiveness of the thinned array is discussed[104]. The every detail theory of phased array from array its inception to application and with computer compatible signal processing, are very elaborately explained in this book[105]. A hybrid method suggested for no uniformly spaced linear and planar array, by sampling the array factor. Later, Fourier coefficient and LMS method is used to solve system equations to determine the excitation current distribution of the array elements[106]. Comprehensive learning particle swarm optimizer(CLPSO) is using a different learning strategy to accelerate convergence of PSO. Array synthesis of unequally spaced linear array is performed using CLPSO algorithm for side lobe suppression and maintain bandwidth and controlling nulls[107]. Simple genetic algorithm is generally taking larger time to solve large array thinning problems. A new simple and fast global optimization method along with GA is proposed in order to improve the numerical efficiency for thinning large arrays which can reduce computation time by 90 percent[108]. An array synthesis strategy for volume scanning from 0° to 60°, in radar communication is suggested using rectangular patch antenna. To generate a high gain radiation pattern, all linear arrays of the rectangular array are steered to such directions so that the resultant radiation pattern produce 60° width beam and this suggested method is verified by FEKO software[109]. Two approaches of side lobe reduction in linear array synthesis are described. In the first attempt, the array design considered array length is the constraint and in another approach, element positions in the array are perturbed. In both of the cases optimization of side lobe level is performed using particle swarm optimization[110]. The conventional very sophisticated optimization algorithm GA and PSO are found not suitable for implementation on digital signal processing chip as well as real time beam forming operation due to large computation time. A multi run strategy in DSP is proposed to modify binary PSO and GA along with hardware usage pattern for in chip implementation to reduce computation time so that can be used in real time beam forming[111]. Array thinning is an off line process of strategically switching off some active elements from the array without distorting the radiation pattern. A method is suggested for dynamic thinning of large arrays using GA for real time operation and this method is applied to linear and planar array optimization[112]. Two different techniques are proposed to produce a wide flat top sector beam pattern using optimization technology. In the first case, flat top beam generation is developed by controlling only the
excitation phase of phased array antenna. Optimization is applied using Visual Basic macros with Microsoft Excel’s solver spread sheet for pattern parameter determination, when the excitation amplitude and inter element spacing is kept fixed. This optimization is applied to various geometry array such as linear, triangular grid and circular grid array to generate rectangular flat top beam pattern and the results are analysed from simulated radiation pattern. In another approach this flat top beam pattern is synthesized by application of differential evolution algorithm, and also improves the pattern quality by lowering side lobe level, very little ripple in the sector area and sharp transition [113-114]. A new array synthesis method is proposed by null insertion in radiation pattern using a new optimization method, ensemble differential evolution (DE) algorithm. The ensemble DE is absorbing the advantageous features of several DE algorithms into a single process. The application of this algorithm targets to find the minimum difference between the observed and desired pattern, which contains nulls in the desired direction, and at last simulation results are compared with simulation pattern from bees algorithm [115]. The very important concept of antenna is explained from the definitions of electromagentic theory to various antenna structures for different application are given in detail in this book [116]. A comparative analysis on design of microstrip antenna using various optimization algorithm such as DE, GA and PSO with their advanced version are reported in details [117]. Circular antenna arrays are very frequently used in modern radar systems. This array synthesis facing a challenge in keeping fixed beamwidth with low side lobe level. An array synthesis method is investigated to counter this challenge by applying optimization using simulated annealing by adjusting inter element spacing [118]. A planar array is designed with Tchebyscheff distribution excitation and Improved PSO algorithm is reported. Tchebyscheff distribution is used to define IPSO search space and the algorithm finds the optimum current distribution for the planar array with maintain half power beamwidth and prescribed nulls [119]. An array thinning problem for shaped beam is explored with a novelty, in using orthogonal matching pursuit algorithm combined with fast full wave analysis method and spherical wave expansion on antenna arrays. The real mutual coupling between the elements is consider to optimize and the non selected elements are switched off from the array, results are applied to microstrip and DRA antennas [120]. The problem of interference suppression in array antenna environment can be done by Schelkunoff method by placing the nulls in desired direction. This array has no control on side lobe level, thus optimization of side lobe level is suggested using PSO and it was evident from the simulated radiation pattern that proposed methods, placing the nulls successfully reduce side lobe levels [121]. Thinned array can reduce interference by lowering
side lobe level in radiation pattern. Various optimization techniques are used before for side lobe level reduction. A new concept of optimization, adaptive GA is suggested here for thinning, but instead of arbitrary array thinning which introduces unnecessary null in the radiation pattern, this proposed method only switching off the required element for a prescribed side lobe level[122]. Direction of Arrival(DOA) estimation is some extent dependent on antenna array configurations. It is observed DOA estimation performance can be enhanced by reconfiguring multi antenna receiver through Cramer-Rao Bound(CRB) selection for isotropic array and Dinklebach algorithm for directional array to maintain optimum selection of the adaptive array with low peak side lobe level[123]. A new array synthesis demonstrated with improved radiation by a new analytical method. In this strategy of array designing the required criteria such as half power beamwidth, side lobe level are kept as target, then the analytical method suggest the number of element and excitation currents which decreases monotonically from the array center to the edge. Simulation results supports this analytical method improve the desirable character with respect to other analytical arrays[124]. Central force optimization(CFO) optimization technique is modified by combining idea of social thinking of PSO with the searching strategy of CFO to enhance the global searching and convergence capability. This MCFO algorithm is tested with 12 benchmark problem and also done array synthesis of unequally spaced array for lowering side lobe level and null placements. The simulations claimed that the MCFO optimization performed better than any other optimization technique like GA[125]. The work in beam shaping technology is limited. Pattern synthesis in beam shaping is intensively investigated by optimizing amplitude and phase of distribution of an array using harmony search and differential evolution algorithm for flat top beam generations. It is evident from the simulation results the proposed method not only good for beam shaping also considerable amount of side lobe level reduced[126]. Sparse array thinning is suggested for beam shaping through optimization using orthogonal matching pursuit (OMP) algorithm and spherical wave expansion. OMP is used to reduce the mutual coupling effect in order to determine element position by thinning[127]. It is presented, the synthesis of flat top sector beam pattern from concentring ring arrays by optimization of element excitation phase and amplitude using DE algorithm. It is also shown this beam has the capability of steering in elevation plane[128]. An array synthesis method proposed for 5G mm wave by optimizing unequal inter element spacing using GA for minimum side lobe level and desired nulls[129]. A lightweight and effective method presented for sector beam pattern generation from a uniform linear array. Optimization problem formulated from approximating the desired array factor response that
solved by assuming closed form real array weight and the solution provides the optimum array weight only the function of beamwidth at any desired direction[130]. A uniform amplitude array synthesis method for minimizing peak side lobe level is proposed, using an effective two step method and keeping minimum element spacing constraint. First, an analytical approach is considered to attain a local unequally spaced optimal array, afterwards an iterative locally adjusting process is adopted to adjust elements spacing which results minimum side lobe level. The simulation and numerical results compared with global optimization process that confirm superiority of this proposed method[131]. J.S. Stone suggested an array synthesis in which array elements are excited by the value from binomial distribution[132]. This array is producing beam pattern with no side lobes when the element spacing is half wavelength.