NINEVAH UNIVERSITY
COLLEGE OF ELECTRONICS ENGINEERING
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Enhancement of Beam Width and Side Lobe Level Using Convex Optimization in Linear, Planar and Random Antenna Arrays

By

Rana Raad Shakir Alobaidy

M.Sc. Dissertation

In

Communication Engineering

Supervised by

Prof. Dr. Jafar Ramadhan Mohammed

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Enhancement of Beam Width and Side Lobe Level Using Convex Optimization In Linear, Planar and Random Antenna Arrays

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بسم الله الرحمن الرحيم

﴿يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنْكُمْ وَالَّذِينَ أُوتُوا

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صدق الله العظيم

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I certify that the dissertation entitled (**Enhancement of Beam Width and Side Lobe Level Using Convex Optimization in Linear, Planar and Random Antenna Arrays**) was prepared by **Rana Raad Shakir** under my supervision at the Department of communication Engineering, Ninevah University, as a partial requirement for the Master of Science Degree in communication Engineering.

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I certify that the linguistic reviewing of this dissertation was carried out by me and it is accepted linguistically and in expression.

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I certify that this dissertation was carried out in the Department of communication Engineering. I nominate it to be forwarded to discussion.

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Publications: -

Some of the important results obtained in this work have appeared in the publication**: -**

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Abstract

In many applications, the radiating elements of the deployed antenna array may be configured in the form of a single linear dimensional, or two planar dimensional or even random distributions. Linear or planar array antennas are considered uniform when the distances between the array elements are regular, and random antenna array when the distances are random. In such applications, a simple optimization algorithm is highly needed to optimally determine the excitation amplitudes and phases of the array elements and maximize the system's performance. In this dissertation, a convex optimization is used instead of other complex global stochastic optimizations to synthesize the linear, planar, and random array patterns under pre-specified constraint conditions. These constraints could be either fixed beam width when minimizing the sidelobe levels or fixed sidelobe levels when minimizing the beam width. First, the problem of obtaining a feasible minimum sidelobe level for a given beam width has been investigated. Then, the problem was reversed to obtain a feasible minimum beam width for a given sidelobe level. Both optimization methods were applied to the linear, planar, and random array configurations. Simulation results verified the effectiveness of both optimization methods and for all considered array configurations. Simulation results show that the feasible minimum sidelobe level can be obtained was (-35.74dB) for 5 deg beam width in the linear antenna arrays. While for the planar and random arrays, the feasible minimum side lobe levels were below -8 dB. This is mainly due to the restriction on the limited aperture area in the planar and random arrays.

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List of Abbreviation

Abbreviation	Name
5G	Fifth Generation
AF	Array Factor
ALO	Antlion Optimization
CAA	Circular Antenna Array
DE	Differential Evolution
EF	Element Factor
FA	Firefly Algorithm
FNBW	Fist Null Beam Width
GA	Genetic Algorithm
GOS	Grasshopper Optimization Algorithm
HPBW	Half Power Beam Width
IWO	Invasive Weed Optimization
LAA	Linear Antenna Array
OLS	Ordinary Least Square
PSO	Practical Swarm Optimization
MIQP	Mixed Integer Programing Problem
MMW	Millimetre Wave
RGA	Real coded Genetic Algorithm
SA	Simulated Annealing
SLL	Sidelobe Level
SOS	Symbiotic Organisms Search
WSN	Wireless Sensor Network

List of Symbols

Symbols	Name
$D(\theta,\Phi)$	**Directivity (Dimensionless)**
D_0	**Maximum Directivity**
dx	**The Spacing of Element in x -axis**
dy	**The Spacing of Element in y -axis**
k	**The Wavenumber**
U	**Radiation Intensity (W/Unit Solid Angle)**
$Umax$	**Maximum Radiation Intensity (Watt/Unit Solid Angle)**
w_{mn}	**Amplitude Excitation of the Elements**
βx	**The Progressive Phase Shifts in x –directions**
βy	**The Progressive Phase Shifts in y –directions**
λ	**The Wavelength in Free Space**
Ω_{BW}	**the required first null to null beam**

CHAPTER ONE
Introduction

1.1 Overview

Low sidelobe levels with narrow beamwidth (i.e., maximum directivity) in radiation pattern are essential in most array antennas applications to reduce the negative impacts of noise and interfering signals, generating misleading target indications and affecting overall system performance. To achieve a minimum sidelobe level, proper antenna array design and structure are required. Antenna arrays can be arranged as linear arrays, planar arrays, or random planar arrays, depending on their applicability in a real-world setting. In the linear and planar arrays, the inter element spacing is usually regular and uniform, while in the random arrays they are irregular and nonuniform. Unlike the linear arrays where their radiation patterns can be scanned either on the azimuth or elevation angles, the radiation patterns of the planar arrays can be scanned to any angle in the azimuth and elevation planes simultaneously. Thus, the planar arrays are widely used in practical application due to their advantages and versatility [1].

The regularly spaced and uniformly excited linear and planar antenna arrays have many good radiation characteristics such as narrow beamwidth, good directivity, and simple excitation weight vector, but they suffer from high sidelobe levels (SLLs) of about -13.2 dB, which may cause many false target indications and many other problems. It is possible to control the beamwidth, sidelobe level, and other array pattern characteristics by adjusting one or more of the following array design parameters, the geometrical layout of the array elements, the excitation amplitudes and phases of the array elements, interelement spacing, and finally the pattern of each individual element [2].

The process of determining antenna settings to obtain desired radiation attributes such as null position, sidelobe level, and antenna pattern beamwidth is known as pattern synthesis. Many methodologies have been developed for the synthesis of linear and planar arrays. Some of the most current intelligent optimization methodologies for array antenna synthesis include the Genetic Algorithm [3], Particle Swarm [4], simulated annealing [5], the differential evolution algorithm [6], and Touring ant colony [7]. However, the computational complexity of these global optimization methods is high, especially when dealing with large arrays. Many antenna problems can be solved analytically or numerically by treating them as or converting them to convex optimization problems [9].

Convex optimization techniques are useful for offering structural insights into the best solution as well as finding optimal numerical solutions to these problems quickly [8]. Convex optimization methods can be used to effectively solve the problem of array synthesis with a feasible minimal sidelobe level for a given beam width or feasible minimum beam width for a given sidelobe level. This chapter includes the literature survey, problem statement, objectives and the aims of the dissertation. It also contains the whole organization of dissertation.

1.2 Literature Survey

In the literature, several analytical and optimization strategies were examined to discover the element excitations or other design parameters that result in a desired radiation pattern with a low side-lobe level [9].

Many scholars researched these design factors in the literature and discovered that the SLL may be lowered by tapering the excitation amplitudes of the array of components. As a result, several tapers based on deterministic equations, such as Dolph, Taylor, triangular, and raised cosine, to mention a few [2], were proposed. Dolph-Tschebyscheff proposed distribution for element excitations such that the appropriate array pattern has the least amount of beam width widening for a given sidelobe level. In other words, as the beamwidth decreases, the sidelobe level increases and vice versa.

In 1997, H. Lebret and S. Boyd ,demonstrated how convex optimization might be used to create the best layout for any antenna array. The procedure either identifies a viable point or unequivocally determines that the issue is infeasible. The major objective was to show how powerful and efficient convex optimization can be for antenna array design syntheses [10].

In 2005, M .Khodier and C.Christodoulou, used the particle swarm optimization (PSO) technique to synthesize linear array geometry with the lowest sidelobe level and null control. The PSO method was successfully utilized to optimize array element positions to produce an array pattern with suppressed sidelobes, null placement in certain directions, or both. Exploring alternative array geometries and adjusting the excitation amplitude and phase of each element in the array can give you more control over the array pattern [11].

In 2007, C. Rocha-Alicano, et al., Combining a binary-coded genetic algorithm (GA) with a differential evolution (DE) approach allowed for the sidelobe level problem in planar arrays to be minimized. When compared to a linear array with uniform inter-element spacing, DE proved to be an effective approach to lower the side lobe level. The use of a GA helped to see which factors are most responsible for controlling the sidelobe levels. When both algorithms are used combined, they demonstrated that they are extremely well suited to this task [12].

In 2007, N.Petrella, et al., used the Practical swarm optimization (PSO) method to create a planar array with the least amount of sidelobe and null control. The method easily met the optimization target in each of the cases provided. The use of particle swarm optimization to construct planar arrays was demonstrated in this research. Its goal was to eliminate sidelobe and insert nulls in certain directions [13].

In 2007, P.J.Bevelacqua and C.A.Balanis, developed a technique for determining the best sidelobe-minimizing weights for an arbitrary linear array for each scan direction, beamwidth and kind of antenna element employed. Using the particle swarm optimization approach, optimal linear array placements are then discovered. This can provide a global bound on antenna array sidelobe reduction performance [14].

In 2008, A. Recioui, et al., discussed the use of genetic algorithms to create uniformly spaced linear array geometries with low sidelobe levels and beamforming capacity. Several examples are provided to show the design's efficacy and adaptability. The Schelkunoff approach, in combination with Genetic Algorithms, has proven to be effective at synthesizing any well-designed and achievable intended radiation pattern [15].

In 2013, J.R. Mohammed, studied the radiation pattern of two extra elements put at both the edge of the original array provides a null in the direction of the original array's main beam, and all of the other lobes of the two-element array are almost at the position of the original array's sidelobes. The initial array was created with the intention of aligning the lobes of both designs. For sum patterns, combining the two patterns reduces sidelobes on one side while increases sidelobes on the other. The sidelobes on both sides are significantly reduced for different designs [16].

In 2014, J.R Mohammed and K.H Sayidmarie, used convex optimization to optimize the excitations of only the perimeter elements of the planar array subject to low asymmetric sidelobe and controlled nulls. In comparison to fully optimized planar arrays, these outstanding radiation properties were achieved at a lower cost and with a simpler feeding network [17].

In 2014, Z.Zhang, et al., showed that the side lobe level of uniformly spaced linear array geometries with a specific main beam width is minimized by using the real-coded genetic algorithm (RGA) optimization approach provided in this research. Utilizing MATLAB, the optimization procedure is completed. With different numbers of elements and intervals between each element, it was compared to traditional analytical techniques like Chebyshev and Taylor. It was discovered to be helpful to use the genetic algorithm to the synthesis of patterns [18].

In 2016, B.Sun, improved the synthesis sparse array by using a unique two-step convex optimization approach. The sparse array's goal and constraints function are eased to make it a convex problem for synthesis of focused and shaped beam patterns. In both non-uniform and thinned array, numerical comparisons show that the suggested technique has reduced side lobe level [19].

In 2016, N. Dib, applied Symbiotic Organisms Search (SOS) that is a robust method to the synthesis of antenna arrays for the first time. It was primarily used to create linear antenna arrays with reduced side lobes. The amplitudes optimization, placements optimization, and phases optimization situations of linear array design were all examined. The results were compared to those produced with conventional optimization approaches, but without the need for modifying parameters [20].

In 2016, A.Safaai-Jazi , et al. , used a novel analytical method for manufacturing evenly spaced linear arrays. These arrays are constructed so that their array factor is the m-th power of the array factor of an n-element uniformly stimulated array. The advantage of technique is that it always results in a monotonically reducing current taper. By removing far-out components with low amplitudes, this feature allows for array thinning [21].

In 2017, S. Ur Rahman et al, calculated and optimized the inter-element spacing and excitation amplitude in this study using the PSO algorithm code. The optimization goals in this work included optimizing the HPBW, SLL, directivity, and null steering in certain rotational directions. The PSO approach has utilized the two fitness functions in order to accomplish these objectives. When using various values for the number of antenna array elements, one of the fitness functions is utilized to determine the ideal excitation amplitude and inter-element spacing values that result in a pattern with the least amount of SLL and HPBW. By maximizing excitation amplitude, PSO uses the second fitness function to regulate the nulls in a certain direction and reduce SLL and HPBW [22].

In 2017, J.R Mohammed, showed that because just the final two edge elements of the huge uniform array are optimized, the directivity and HPBW are unaffected. With pre-specified width and depth, the optimized approach may achieve the needed sidelobe nulling. More importantly, the suggested array requires a fairly simple feeding network to be implemented. As a result, it might be regarded the most practicable way for implementation. Additional degrees of freedom must be included in the optimization process to generate multi-sectors sidelobe nulling [23].

In 2017, S.Saleem, et al., focused on optimizing linear array synthesis to obtain shorter half-power beam widths, lower side-lobe levels, and nulls management as required by the design. To achieve these objectives, researchers looked into optimizing the array's excitation amplitude, phase, and inter-element spacing. Particle Swarm Optimization (PSO), which used a fitness function created using null direction and side lobe level (SLL) restrictions, was used to optimize the design variables [24].

In 2018, G.Sun, et al., examined the synthesizing of the beam patterns of the linear antenna array (LAA) and the circular antenna array (CAA). The maximum sidelobe level (SLL) of the beam patterns is first reduced using an optimization algorithm. The invasive weed optimization (IWO) algorithm is then used to solve the specified issue. When compared to other algorithms for SLL reductions, the findings revealed that IWO performs better in terms of accuracy, convergence rate, and stability [25].

In 2019, J.R. Mohammed, designed an arbitrary array with randomly distributed components to create the desired beamforming shape successfully and effectively. Convex optimization used to optimize the amplitude and phase of each random element. Using the compressed sensing approach, more research might be done to improve array performance with a fewer amount of random elements [1].

In 2019, J.R. Mohammed, presented two novel strategies for synthesis of array patterns that accomplish deep side-lobe reduction. The suggested approaches, unlike previous sidelobe reduction methods, utilize a novel process based on the derivation of a cancellation pattern. The method consists of the following steps: first, the element excitations of an array are disturbed sufficiently so that the corresponding array factor produces a specified cancellation pattern; second, the original array is subtracted from the original, uniformly excited array to get a new array pattern [26].

In 2019, H.Yang, et al., the proper configuration of uniformly stimulated and evenly spaced arrays is advised in order to produce the desired amplitude distributions in the main planes. The 9-element array's SLL in both the E and H planes is less than -27 dB. This approach and strategy might be useful in situations when high gain and low SLL are required [27].

In 2020, A. Amaireh, et al., used two metaheuristic algorithms, Antlion optimization (ALO) and Grasshopper Optimization algorithm (GOA) to optimize the design of scanning linear antenna arrays. The goal of this work was to minimize the side lobe level while keeping the major lobe beamwidth constant. When compared to other approaches such as SOS and FA, the findings revealed that the suggested hybrid algorithm is quite competitive in lowering SLL [28].

In 2021, Y.X.Zhang, et al., suggested a solution framework for antenna array directivity maximization issues based on convex optimization approaches. The relationship between the problem and the techniques for solving it has been thoroughly studied. The presented techniques may be used to optimize arbitrary antenna arrays with fixed element placements and pre-determined element radiation patterns. The two-stage technique may lead to extremely good solutions even under very strict SLL constraint conditions [29].

In 2021, F.Yang et al., provided an effective optimization strategy for the synthesis of sparse arrays. In which, the directivity was entirely optimized and the maximum array aperture was restricted. A broad real-value mixed integer programing problem (MIQP) issue for maximizing the sparse rate in a constrained array aperture was construct based on the framework of thinned array synthesis. The iterative convex optimization approach was then suggest as a solution to this problem [30].

In 2021, M.Khalaj-Amirhosseini, suggested an analytic approach for designing uniformly spaced arrays with the lowest feasible sidelobe level and directivity as near to that of uniformly excited arrays was suggested. The sidelobe levels of the synthesized array may be regulated by the expansion factor, which is proportional to the beamwidth of the main lobe of the optimum desired array factor [31].

In 2022, Ayşe Müge Zobu et al, to achieve low side lobe levels, the antenna array with a feeding network proposed in this study .This paper described the design process for a feeding network that makes use of Dolph-Tschebyscheff distributed coefficients. This array was designed to obtain a side lobe level of -20 dB. Coefficients were used to create the shunt linked series-feeding network. The feeding network's output has delay lines added to it, which directs the antenna's radiation pattern in the desired directions. The obtained side lobe level was below -15 dB [32].

In 2022, M.Khalaj-Amirhosseini, designed Linear antenna arrays to provide the highest possible directivity for a given beamwidth. The excitation currents were calculated using the Lagrange multiplier approach and a matrix equation. The effectiveness of the suggested technique is investigated using several examples. The synthesized arrays' directivity is proportional to the number of element [33].

1.3Problem Statement

In many applications, the performance of the antenna arrays may be not appropriate due to high sidelobe level, wide beam width and low directivity. Thus, the antenna array may suffer from interference and performance degradation.

The array design should be as simple as possible so that the practical implementation can be achieved properly.

A simple optimization method is highly wanted to design such antenna arrays with the requirements to enhance the energy in the main lobe, i.e., raise the directivity while lowering the power wasted in the side lobes.

1.4 Objectives and Aims of the Dissertation

- To investigate the performance of three configuration of antenna arrays linear, planar and random planar array.
- To study and compare Half Power Beamwidth (HPBW), First Null Beamwidth (FNBW), Directivity and Side Lobe Level (SLL).
- To use convex optimization to optimize array performance under certain restrictions for some constants in the radiation pattern.
- By optimizing the excitation amplitude and phase of the individual array elements, the convex optimization was applied to the linear, planar, and random arrays to generate the required radiation patterns.
- To use two constraint techniques to carry out the optimization procedure. The first one includes the feasible minimum sidelobe level for a given beam width, while the other one includes the feasible minimum beam width for a given sidelobe level. Both methodologies' efficacy in building linear, planar, and random arrays was demonstrated and validated.
- To employ the convex optimization function within the Matlab program with CVX_function [34] to meet the research's goals.

1.5 Layout of the Dissertation

The dissertation is divided into five chapters. Chapter two explores the background and the theory of antenna array types and its parameters. Chapter three presents convex optimization method and the way to use it in optimized the three types of antenna arrays. Chapter four presents the simulation results of optimizing the amplitude and phase excitation for each elements in the linear, planner and random planner array first to obtain feasible minimum sidelobe level for a given beam width, while the other one includes the feasible minimum beam width for a given sidelobe level. Chapter five gives the conclusions and some suggestion for future work.

CHAPTER TWO

Theoretical Background of Array Antennas

2.1 Introduction

Single antennas are generally limited for many applications because of the large half power beamwidth and lower Directivity. To satisfy the demands for long distance communication, high-gain and narrow pencil beam, it is sometimes required to construct antennas with particularly directional properties. Increasing the antenna's electrical size is typically the only way to do this. Because most antennas are on the order of a wavelength, and because beamwidth is inversely related to antenna size, many antennas are necessary to sharpen the radiation beam. Without necessarily increasing the size of the individual pieces, another efficient method is to arrange the radiating components into an assembly in a geometrical and electrical structure. An antenna array is a type of multi element radiation device [30]. An array of antennas that work together to focus energy reception or transmission in a specific direction might extend a system's usable range [35].

The capacity of a communication system has constraints as a result of the fast development of communication technology and the explosive expansion in the number of users. Antenna arrays can help wireless communication system by increasing capacity and spectrum efficiency. For example, to increase the system's spectral efficiency and transmission rate, fifth-generation (5G) communications use millimeter wave (mm-wave) and beamforming technologies based on antenna arrays. Additionally, utilizing antenna arrays can improve the energy efficiency of a communication system [25].

In comparison to a single element, an array provides various benefits. Before merging the signals, the signals can be weighted to improve performance aspects like interference rejection and beam steering without actually altering the aperture. It is even conceivable to design an antenna array that can change how it operates based on its surroundings. These appealing characteristics come with an increased expense and complexity [36].

In this chapter, the main antenna array parameters as well as the array geometries are presented. The array parameters may include, array radiation pattern in both linear and dB scales, directivity, sidelobe level, and the half power beam width. Where the array geometries will include single dimensional linear array, two dimensional rectangular planar array, and random planar array where its elements are randomly distributed along xy-plane. Moreover, the most significant and well-known relationships and array design parameters will be discussed and explained in this chapter

2.2Antenna Array Parameters

Definitions of many criteria are required in order to define an antenna's performance. Not all of the characteristics must be included for a thorough description of the antenna performance because some of them are interrelated.

2.2.1 Radiation Pattern

An antenna radiation pattern or antenna pattern is defined as "a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates. In most cases, the radiation pattern is determined in the far-field region and it is represented as a function of the directional coordinates. Radiation properties include power flux density, radiation intensity, field strength, directivity, phase or polarization." [2].

In another word diagrammatic representations of the distribution of radiated energy into space, as a function of direction, known, as radiation patterns. An antenna's radiation pattern serves as a representation of the energy it emits. The two- or three-dimensional spatial distribution of radiated energy as a function of the observer's location along a path or surface of constant radius is the radiation property of most interest. An antenna's spatial response may be evaluated qualitatively overall using three-dimensional antenna patterns. However, two-dimensional cuts are necessary to get accurate sidelobe levels, null positions, and beamwidth measurements. The two-dimensional antenna pattern measured on a large circle surrounding the antenna is known as an antenna pattern cut. It is common practice to normalize the field and power patterns in relation to their maximum value, resulting in normalized field and power patterns. Additionally, the power pattern is sometimes represented in decibels or on a logarithmic scale (dB). This scale is typically preferred because a logarithmic scale helps emphasize in greater detail the small lobes, or extremely low value portions of the pattern. Rectangular plots of these identical patterns may be seen in (dB) and in (linear). The nulls, beamwidth, and sidelobe levels are exactly located using the rectangular plots as show in figure (2.1). In contrast to the dB plot, low side lobes are more difficult to notice in the linear display [36].

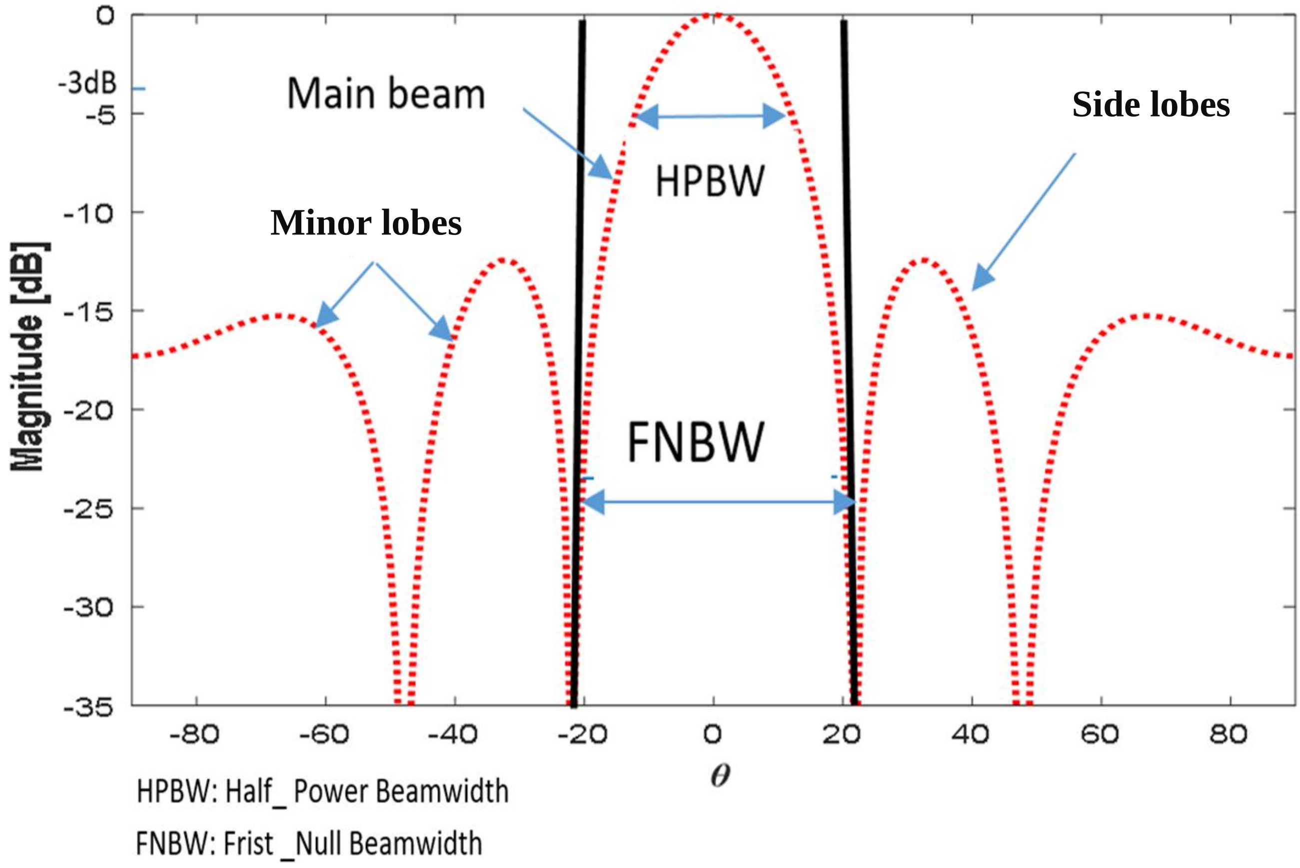


Figure (2.1): Plot of Power Pattern and its Associated Lobes and Beamwidth.

2.2.2Radiation Pattern Lobes

The term lobe refers to a number of different components of a radiation pattern, which can be further divided into major or main, minor, side, and back lobes, according to the figure (2.1).

A radiation lobe is define as "portion of the radiation pattern bounded by regions of relatively weak radiation intensity."

A major lobe (also called main beam) is defined as "the radiation lobe containing the direction of maximum radiation." The main lobe or major lobe is the largest portion of the radiated field, which extends across a wider region. This is the area where the amount of radiation is at its highest. This lobe's orientation reveals the antenna's directivity.

A side lobe is “a radiation lobe in any direction other than the intended lobe.” A minor lobe is any lobe except a major lobe. Side lobes or minor lobes refer to the other areas of the pattern where the radiation is spread side wards. These are the places where energy is being misused.

There is another lobe that faces the main lobe in the exact opposite way. It is referred to as the back lobe and is a small lobe. A back lobe is “a radiation lobe whose axis makes an angle of approximately 180◦ with respect to the beam of an antenna.”[2] .Even here, a lot of energy is lost. Additionally, it has been demonstrated that the array creates extra beams (grating lobes) if the inter-element spacing is equal to or greater than one wavelength. It is important to understand how a grating lobe varies from a typical side lobe. Side lobes are a result of both positive and negative interference from the antenna's many radiating components. A side lobe's level is always lower than the main beam's. A grating lobe is created in directions where there is a maximal in-phase addition of radiated fields due to the periodicity in the radiation pattern. Instead of being compared to a typical side lobe, a grating lobe should be contrasted with the main beam [37]. In the linear antenna array has just one beam peak inside the observable observation angle area ($-90^0, 90^0$) if the distance between the neighboring elements is equal to or less than the wavelength λ. The undesirable grating lobe arises when $d > \lambda$. In order to prevent the appearance of the grating lobe, the value of the maximum element spacing is determined by the observation angle range.

2.2.3 Side Lobe Level (SLL)

A ratio of the power density of a particular lobe to that of a major lobe is typically used to represent the level of minor lobes. This ratio is commonly referred to as the side lobe ratio or side lobe level [38] .The side lobe level defined as "The maximum relative directivity of the highest sidelobe with respect to the maximum directivity of the antenna" [39].

2.2.4 Directivity

The directivity is a metric used to compare a given antenna to an isotropic antenna emitting a similar amount of power. In other words, the directivity is the ratio of an anisotropic antenna's power density to that of an isotropic antenna emitting a given amount of power [40].

Therefore directivity of an antenna defined as "the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions. The average radiation intensity is equal to the total power radiated by the antenna divided by 4π. If the direction is not specified, the direction of maximum radiation intensity is implied [2].

$$D(\theta,\emptyset) = \frac{4\pi U(\theta,\emptyset)}{\int_0^{2\pi}\int_0^{\pi} U(\theta,\emptyset) sin(\theta) d\theta d\emptyset} \qquad (2.1)$$

The greatest directivity is a fixed quantity and is just Equation (2.1)maximum . D_0 is often used to indicate the highest directivity. As a result, by slightly altering Equation (2.1), the highest directivity may be discovered to be

$$D_0 = \frac{4\pi U_{max}}{\int_0^{2\pi}\int_0^{\pi} U(\theta,\emptyset) sin(\theta) d\theta d\emptyset} \qquad (2.2)$$

Where

D = directivity (dimensionless)

D_O = maximum directivity (dimensionless)

U = radiation intensity (W/unit solid angle)

Umax = maximum radiation intensity (W/unit solid angle)

2.2.5 Antenna Beamwidth

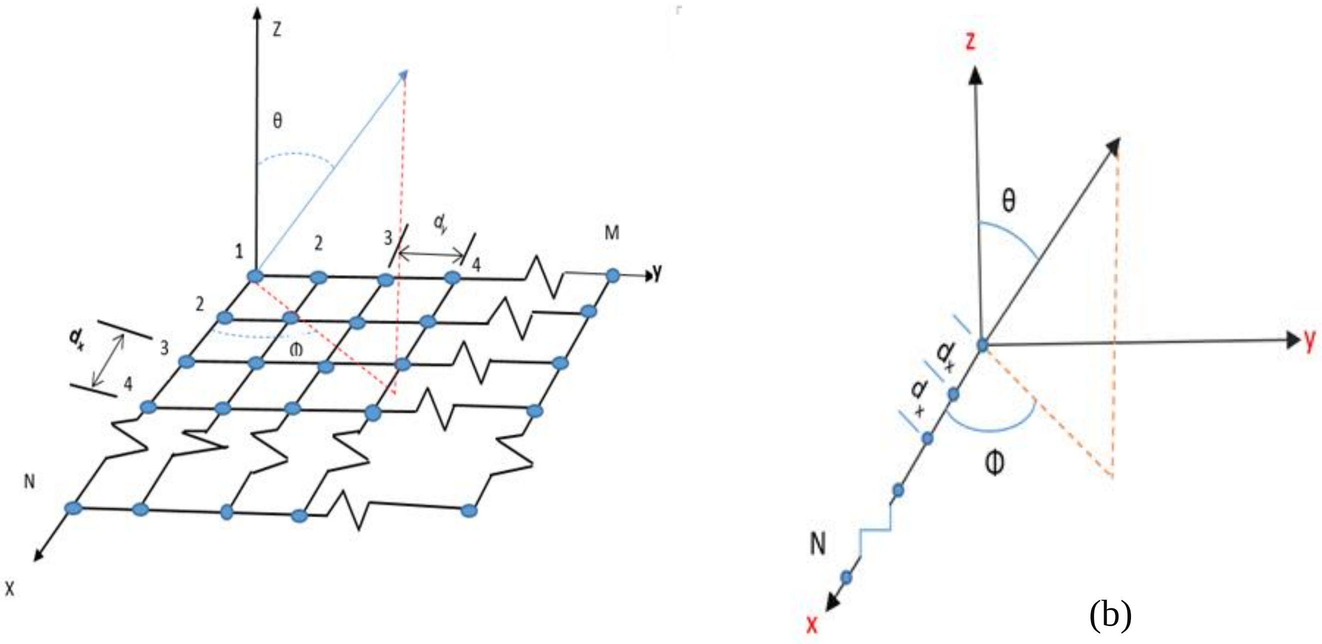
It could be used to compare gains between antennas. The gain, on the other hand, is a number that simply uncovers information about the maximum radiation. commonly wonder what the shape of the radiation belt is. It makes use of the beamwidth for that. It can determine the shape of the main lobe from the beamwidth. Beamwidth has a variety of meanings [37].

The Half-Power Beamwidth (HPBW) is one of the most used beamwidths, which is defined by IEEE as: "In a plane containing the direction of the maximum of a beam, the angle between the two directions in which the radiation intensity is one-half value of the beam." However, in actual usage, the HPBW is typically referred to as beamwidth without any extra identification. In other words, the beam width is the region where the peak power, or the majority of the power, is emitted. Half power beam width is the angle in the antenna's effective radiated field when the relative power is more than 50% of the peak power. Half power beam width, or HPBW, is the angle between two vectors when a line is drawn from the origin of the radiation pattern to the half power locations on the main lobe, on both sides. As the beamwidth drops, the side lobe grows, and vice versa, the antenna's beamwidth is a crucial figure of merit that is usually utilized in trade-offs with the side lobe level.

The angle between the pattern's first nulls, also known as the First-Null Beamwidth (FNBW), is another significant beamwidth .FNBW is just the angle measured between the first null points of the radiation pattern on the major lobe and quoted away from the main beam. Drawing tangents on both sides, tangential to the main beam, commencing at the radiation pattern's origin, is a sign of FNBW. First Null Beam Width is the angle formed by those two tangents (FNBW) [38].

2.3 Antenna Array Configurations (Linear, Planar, Random)

Any geometric shape is possible for arrays of antennas. Linear arrays, circular arrays, planar arrays, and conformal arrays are some of the array geometries of importance [40]. The designer must not only choose the appropriate radiating elements but also take into account the geometry (placement) and excitation of each individual element in order to synthesize the overall pattern of an array. The layout of the items and their kinds also affect how well the array performs. To help the designer choose an efficient array structure, trade-offs for linear and planar arrays are described. As was said before, an array of sensors alters the pattern of the array as well as the gain and bandwidth of a single sensor. The array resolution and interferometer (grating lobe) effects are determined by the location of the components within the array. Resolution often rises as array dimension (or the distance between items) grows [41]. Physical restrictions determine the geometry, and the designer may have limited in choosing the array geometry. The linear array with uniform spacing and the rectangular planar array with uniform and non-uniform inter element spacing will be the two types of antenna array configurations that will be the subject of this thesis's study, which will also examine their performance and optimization using convex optimization .



(a)

(b)

Figure (2.2): (a) Planar Uniform Array (a) Linear Uniform Array.

2.3.1 Linear Array

The most fundamental configuration for array elements is the linear array shown in figure (2.2 b). Since linear arrays are mostly used in wide application, it is possible to use the same techniques to operate more intricate array forms. The pattern properties of an array may be defined for functioning as a transmitter or receiver, depending on which is most convenient, since antennas often match the reciprocity criterion. The output of each element may be modified in terms of amplitude and phase. Amplitude and phase control enable the radiation pattern to be manipulated and scanned in space [42].

The element factor (EF) and the array factor (AF) may always be used to calculate the far field from an array of identical elements. Pattern multiplication is a characteristic that may be seen in action by the simple fact that the antenna pattern can be multiplied by the array factor pattern. As a result, any array of antennas' far field pattern is always given by (EF) × (AF).

E (total) = [E (single element at reference point)] × [array factor]

The AF is influenced by the electrical phase, spacing, and geometrical configuration of each element in the array [37].

Each array's factor is unique. If the elements' amplitudes, phases, and spacing are the same, the array factor will have a simpler form. The array factor may be calculated by substituting isotropic (point) sources for the actual radiating components since it is independent of the directional properties of the elements themselves. It is assumed that each point source has the same amplitude, phase, and position as the element it is replacing. This type of antenna array named as uniform linear array. “uniform linear array: A linear array of identically oriented and equally spaced radiating elements having equal current amplitudes and equal phase increments between excitation currents” [36].The array factor can be distinguished from the element factor. The array factor may be determined for any array, regardless of the individual elements used, as long as they are all the same. As a result, it is simpler to examine arrays of isotropic items first. When the general array design is finished, the design may be put into practice by adding the necessary specialized antenna parts. These antenna components might consist of patch antennas, waveguide apertures, loops, horns, dipoles, and loops, among others [40].

The array factor of uniform linear array of N elements of isotropic source and each element has β the progressive phase lead current excitation relative to the preceding one with space between elements equal to d is given by [40].

$$AF = \sum_{n=1}^{N} e^{(n-1)\psi} \quad (2.3)$$

$$where \ \psi = kd\cos\theta + \beta \quad (2.4)$$

$$k = \frac{2\pi}{\lambda} \quad (2.5)$$

The array factor in Equation (2.3) of the isotropic elements were considered to have a unity amplitude in the preceding calculation for the array factor. This assumption allows the AF to be reduced to a simple series. The greatest sidelobes for a linear array with uniform weights are down around 24% from the highest value. The array is emitting energy in untended directions if sidelobes are present. Additionally, the array is getting energy from unexpected directions as a result of reciprocity. The sidelobes may pick up the same signal from different directions in a multipath environment. This is the underlying cause of the fading in communications. It is recommended to direct the beam in the intended direction and shape the side lobes to exclude unwanted signals if the direct transmission angle is known [40]. Side lobes may be suppressed by weighting the array elements as show in the figure (2.3).

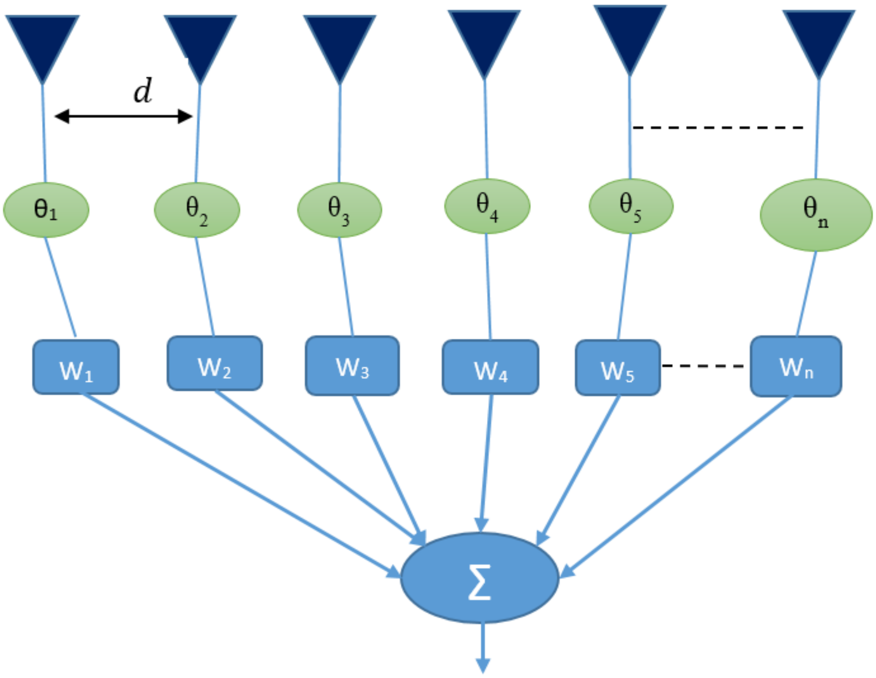


Figure (2.3): Linear Array with Weighting.

The array factor will become as equation (2.6) for the symmetric linear array with an even number of elements N.

$$AF_{even} = \sum_{n=1}^{M} w_n \cos\big((2n-1)u\big) \tag{2.6}$$

Where $u = \frac{\pi d}{\lambda} \sin\theta$ (2.7)

Where 2M = N = total number of array elements. When the argument is zero, the array factor is at its maximum, which implies that θ= 0. The total of all the array weights is thus the maximum.

To obtain the quasi-normalized odd array factor, we may once more add up all of the exponential contributions from each element of the array [40].

$$AF_{odd} = \sum_{n=1}^{M+1} w_n \cos(2(n-1)u) \tag{2.8}$$

Where 2M+1=N. The weights w_n represents the amplitude and phase excitations of the N element uniform linear antenna and can be uniform or can be in any form according to the designer’s needs. The array weights can be optimized by using any optimization algorithm to find the required array parameters. This issue will be discussed and present in the next chapter.

2.3.2 Planar Array

Individual radiators may also be arranged in a rectangular grid to create a rectangular or planar array in addition to arranging elements in a line (to produce a linear array) as shown in figure (2.2 a). With planar arrays, you have more control and shaping options for the array's pattern. The flexibility of planar arrays is greater, and they can produce more symmetrical designs with smaller side lobes. Additionally, they may be used to scan the antenna's main beam in any direction. Radar tracking, search, communications, remote sensing, and many more uses are examples of applications [2].

Following the investigation of planar arrays may go to a few somewhat more complicated geometries by determining the pattern for rectangular planar arrays. An M ×N array of elements created when there are M items in the x-direction and N elements in the y-direction. The weight of the m-nth element is w_{mn}. Both the x- and y-directed elements are separated by dx and dy, respectively. It is possible to think of the planar array as either N linear arrays of M elements or as M linear arrays of N elements. We begin by assuming that the planar array antenna's elements are arranged on a regular grid or lattice, just as we did with the linear array antenna. Although this is not essential for the operation of an array antenna, it will simplify the conversation and depict the scenario that occurs in real-world settings the most regularly. We assume the lattice to be rectangular.

We can use pattern multiplication to identify the pattern of the full M N element array because we already know the array factor for a M or N element array operating alone.

By multiplying patterns, we have [2].

$$\boldsymbol{AF} = \boldsymbol{AF_x} \times \boldsymbol{AF_y}$$

$$AF(\theta,\emptyset) = \sum_{n=1}^{N}\sum_{m=1}^{M} w_{nm} e^{j\frac{2\pi}{\lambda}[(n-1)(d_x sin(\theta)\, cos(\emptyset)+\beta_x)+(m-1)(d_y\, sin(\theta)\, sin(\emptyset)+\beta_y)]} \quad (2.9)$$

The weightsw_{nm} represents the amplitude and phase excitations of the (n,m) element and can be uniform or can be in any form according to the designer's needs. where λ is the wavelength at the operating frequency, θ and ϕ is the elevation and azimuth angles, respectively, if beam steering is desired then the phase delays βx and βy are given by [2].

$$\beta_x = -kd_x sin\theta_0 cos\emptyset_0 \quad (2.10)$$

$$\beta_y = -kd_y sin\theta_0 sin\emptyset_0 \quad (2.11)$$

In the above equations, observe that the array weights can be optimized by using any optimization algorithm to find the required array parameters. This issue will be discussed and present in the next chapter.

2.3.3 Random Planar Array

A typical planar array of sensors cannot be constructed in many applications owing to practical reasons. These include the localization of tumors in biomedical research, environmental sensing such as water quality monitoring, traffic management, seismic exploration, radio telescopes made up of several randomly placed sensors, the detection of forest fires, and flood control. In recent times, both military and civilian applications have successfully deployed wireless sensor networks (WSN) in monitoring regions. These applications include placing sensors across an area where a phenomenon is to be observed. The sensors are employed in the military to identify enemy incursion, while in civilian applications, they are utilized to identify geo-fencing around gas or oil pipelines [43]. The sensor nodes in each wireless sensor network should be configured to function as a smart array or to collaborate in beamforming in order to get the best performance in all of the aforementioned applications. If the array components inside the constrained region exchange information and broadcast synchronously, a steerable beam may then be produced to scan the horizon and determine the required direction. The sensors in this system are randomly arranged across an arbitrarily restricted region, in contrast to the uniformly distributed planar arrays. An antenna with a single element makes up each sensor node. It is better to combine these random nodes into an array than to use a single element antenna or even a straightforward linear array. The primary goal of the arbitrary arrays, which are made up of a random collection of sensor nodes, is to enhance the performance of a wireless sensor network by allowing these random components to cooperate in beamforming. The coherent or incoherent combination of each sensor node yields the overall electromagnetic fields of such arbitrary arrays. As a result, the position, phase, and amplitude excitation of each array member may be used to control the radiation pattern in the far-field area of an arbitrary array with randomly dispersed elements [1].

For random arrays, the elements are randomly located along the x and y-axes and the interelement spacing is irregular. Thus, (can be rewritten as

$$AF(\theta,\emptyset) = \sum_{n=1}^{N}\sum_{m=1}^{M} w_{nm} e^{j\frac{2\pi}{\lambda}[(n-1)(x_{n,m} sin(\theta)\, cos(\emptyset)+\beta_x)+(m-1)(y_{n,m}\, sin(\theta)\, sin(\emptyset)+\beta_y]}$$

(2.12)

Where $x_{n,m}$ and $y_{n,m}$are the random locations of the (n, m) element.The weights w_{nm} represents the amplitude and phase excitations of the (n,m) elements of the random planar array which used to optimized the antenna array pattern [2].

From (2.9) and (2.12), it is clear that the total number of the adjustable excitation elements,w_{nm}, is $N \times M$ which is quite large and ,thus, the use of global stochastic optimizations such as genetic algorithms is associated with high complexity and slow convergence. Further, in many cases, the optimal solution may not require such a highly complex and global optimization algorithm since the searching spaces may be convex. Instead, this problem can be solved efficiently by the convex optimization where the unknown array excitations,w_{nm} , constitutes a set of linearfunctions on a convex space.

The fundamental benefit of the analysis described in the preceding paragraphs is that it is straightforward, making it possible to develop a computer program that can quickly analyze a large number of configurations and, as a result, optimize designs within certain user-defined limitations.

CHAPTER THREE

CONVEX OPTIMIZATION

3.1 Introduction

An effective way to identify and analyze signals coming from many directions is to use antenna arrays. An array of sensors' beam pattern may be altered by an amplitude and phase distribution known as the array's weights, as opposed to a single antenna, which has constrained directivity and bandwidth. The antenna array beam pattern is produced by summing and weighting the signals after preprocessing the antenna outputs. Finding weights that meet a set of requirements on the beam pattern is the core of the antenna array pattern synthesis challenge. In this study, stress the use of convex optimization in the planning of antenna arrays. Of course, not every issue with antenna array design is convex. Nonconvex issues include those where the antenna weights have a fixed magnitude (i.e., phase-only weights), those with lower bound constraints (contoured beam antennas), and situations where the number of nonzero weights is constrained. However, some significant synthesis issues are convex and may be resolved by recently developed extremely effective methods. Furthermore, a particularly strong version of "solution" is meant here: Global solutions are discovered with computing times that are consistently minimal and increase smoothly with the size of the issue. Although the quantity and diversity of issues that may be addressed are substantially greater, the calculation time is naturally not as short as that required by a "analytical" technique. On the other end of the spectrum, nonconvex optimization, which is entirely universal, may be used to formulate any synthesis issue.

The drawback of using such approaches is that they cannot provide global optimality, quick computation, or a smooth increase in computation time as a function of issue size. Convex optimization offers a superior efficiency/generality tradeoff compared to both the (quick but constrained) analytical approaches and the (slow but thorough) general numerical procedures [10]. One of the most significant methods in the area of mathematical programming, which has several applications, is convex optimization. It also applies to fields like machine learning, data science, economics, medicine, and engineering on a far wider scale than just mathematics.

3.2 Convex Optimization

Searching for variables that reach the global maximum or minimum of the sum function is known as optimization. Convex optimization is a subset of optimization where you work with "convex" functions, which simply mean "bowl-shaped" functions. This makes finding maxima and minima easy since you can just get there by walking on the bowl's surface in the direction with the most slop. Convex uses the common comparison operators =, $\leq$, and $\geq$ to specify constraints. They outline the relationships that two expressions must have [44].

Convex optimization problems are of the following two types:

1. Constrained convex optimization: The convex function to optimize is subject to convex constraints.
2. Unconstrained convex optimization: The convex function to optimize is not subject to any convex constraints.

The convex optimization algorithm is optimization for convex function in the condition of convex constraint. Both equality constraints and inequality constraints are applied to the objective function. While equality constraints demand that the answer reside precisely at a certain location, inequality constraints suggest that the solution should be in some range. An inequality constraint for a convex problem states that all variables must be bigger than or equal to zero (or alternatively less than or equal to zero).

$$f_i(x) \leq 0\ ,\quad i = 1, \ldots., m \qquad (3.1)$$

$$h_i(x) = 0, \quad i = 1, \ldots\ldots, p \qquad (3.2)$$

Where f_i(x) are the inequality constrain function, and $h_i(x)$ are the equality constraint function .

This kind of convex function can never become trapped at a local minimum that isn't a global minimum since its gradient always points upward. Two gradients on opposing sides of the graph cannot slope up and down simultaneously because they are not differentiable at the point of junction. This means that when utilizing convex optimization techniques there is no need for iterations because they just move downhill until they reach the optimal value. Convex minimization or convex maximization problems can be used to tackle convex challenges. An algorithm may be improved via convex optimization, which will optimize the rate at which it converges to the answer.

Convex optimizations include convexity, which is crucial. The first derivative of a convex function's continuity is referred to as convexity. It makes sure that convex optimization problems are smooth and have specified derivatives so that gradient descent may be used. Linear, quadratic, absolute value, logistic, and exponential functions are a few examples of convex functions.

As a result, changing the element excitations and setup to have control over the aforementioned parameters creates a complicated issue that may be solved using a variety of techniques. In order to identify the right solution with the necessary properties without thoroughly examining all the alternatives in the solution space, numerical optimization methods are frequently utilized

Convex sets are the most significant for convexity. Any set that has all of the points on or inside of its boundary and all convex combinations of points in its inside is said to be convex. A collection of all convex functions is referred to as a convex set. The convex function, to put it simply, is shaped like a hill. The global maximum or minimum of a convex function is hence what constitutes a convex optimization problem. Because convex sets may be used to modify a convex function through certain sorts of operations to maximize or minimize a convex function, convex optimization approaches frequently employ convex sets. A convex hull, which is the smallest convex set that may contain a certain convex set, is an illustration of a convex set.

On every convex interval, a convex function only takes the value between its minimal and maximal values. This indicates that this convex function has no local extremes (on the convex region). Additionally, it shows that just one point in this group of points that are on the convex hull is closest to the minimum.

Convex optimization is widely used in both combinatorial optimization and global optimization to determine boundaries on the optimal value and approximations of solutions [45].

Convex objective function and constraint function optimization problems have both of these characteristics. The fact that every local optimum solution is also the global optimal solution is a key and significant characteristic of the unconstrained convex optimization problem. This optimization method is only applicable to the problems that can be specified as a convex and its solution is with such convex cone. Convexity is essential for both objective functions and constraint functions. In the case of objective functions, convexity ensures that any local optimal solution is also the global optimal solution if the feasible region is a convex set. In the case of constraint functions, convexity ensures that the feasible region is a convex set and that neither is dispensable. On the other hand, will not be able to acquire the significant property that the local optimal is also the global optimal if just the objective function is convex but the constraint functions are not.

There are several contexts in which convex optimization issues are used: A fundamental class of unconstrained convex optimization problem is the ordinary least square (OLS) regression in statistics [46].

The wanted an algorithm whose performance is unaffected by the initial situation and quickly approaches the ideal outcome. Normally, this would be challenging to estimate, however because its convexity, can assess constraints on how far from optimum the result is.

3.3 Advantages of Convex Optimization

Recognizing or expressing an issue as a convex optimization problem has several benefits as follows:

1. contains particular examples of least-squares issues and linear programs that can be solved precisely and have a comparable level of complexity as linear programs [45].
2. It is true that the inverse image of a convex set under a linear transformation is also convex, and vice versa [45].
3. The most fundamental benefit is that convex optimization techniques may then be used to address the issue in a highly efficient and reliable manner. These problem-solving techniques are trustworthy enough to be included into real-time reactive or automated control systems as well as computer-aided design or analysis tools.

4. If a convex set consists of more than one point, it is linked and has feasible directions at every point. This is essential for optimization since it enables a calculus-based comparison of the cost of x with the cost of its near neighbors and serves as the foundation for several crucial algorithms. Furthermore, convexity eliminates a large portion of the complexity that is frequently related to discrete constraint sets (arising, for instance, in combinatorial optimization) [47].
5. The formulation of an issue as a convex optimization problem also has theoretical or conceptual benefits. When the corresponding dual problem is taken into account, for instance, the original problem might sometimes be interpreted in an intriguing way that leads to an effective or widespread solution [45].
6. It can see that convexity is more inclusive than linearity since inequality takes the role of the more constrained equality and only applies to certain values of and. It may think of convex optimization as an extension of linear programming as each linear program is a convex optimization issue [45].
7. Tractable, both in theory and practice [45].

3.4 Mathematical Optimization

A convex optimization problem is one of the form [45].

Minimize $f_0\,(x)$

Subject to$f_i(x) \leq b_i,\;\; i = 1, \dots \dots .., m$

Where the functions $f_0, \dots .., f_m: R^n \rightarrow R$ are convex, i.e., satisfy

$$f_i(\alpha x + \beta y) \leq \alpha f_i(x) + \beta f_i\;(y)$$

For all $x, y \in R^n$ and all $\alpha, \beta \in R$ with $\alpha + \beta = 1$, $\alpha \geq 0, \beta \geq 0$.

In this work, the function f(x) will be considered as an array factor of the antenna array and the optimization conditions will be representing the desired constraints such as sidelobe level or main beam width.

Gain in the direction of the desired signal must be enhanced while gain in the direction of the interfering signals must be lowered in order to improve the reception of a desired signal. By correctly changing the signal amplitude or phase at all or part of the components, this objective is achieved. An array that has its amplitude tapered or thinned results in low side lobes at the necessary angles. The amplitude of interference entering the side lobes is proportional to the sidelobe level.

Optimal multichannel filtering is an issue in optimal array processing. In a signal environment with many interference signals, the goal of array processing is to improve the receipt (or detection) of a desired signal, which may be random or deterministic. It may be useful to estimate one or more unknown properties that the desired signal may include, such as its geographical position, signal energy, or phase. The employment of complementary techniques, such as the insertion of restrictions, minimizes any performance loss caused by departure of the actual operating circumstances from the expected ideal ones. Vector weighting of the input data successfully matches the desired signal when used under the aforementioned ideal circumstances [41].

In many circumstances, the cost per sensor is substantial due to the sensor and related electronics. As a result, even if space is available, prefer to enhance processing complexity in order to limit the number of sensors.

There is a significant incentive to optimize processing performance.

In many circumstances, the "optimal array processor" will use one of the beamforming designed using deterministic methodologies as a fundamental building component in its implementation [48].

3.5 The Convex Optimized Method

A regularly spaced two dimensional rectangular planar array composed of N rows and M columns of isotropic elements is considered. The elements are distributed uniformly on the xy plane with separation distances $d_x = {}^{\lambda}/_{2}$ and $d_y = {}^{\lambda}/_{2}$ on the x and y directions, respectively. For uniformly spaced linear arrays, the array size will be either $N \times 1$ or M $\times 1$
according to the considered axis. In general, the array factor of two-dimensional elements can be given by:

$$AF(\theta,\emptyset) = \sum_{n=1}^{N}\sum_{m=1}^{M} w_{nm} e^{j\frac{2\pi}{\lambda}[(n-1)(d_x sin(\theta)\, cos(\emptyset)+\beta_x)+(m-1)(d_y\, sin(\theta)\, sin(\emptyset)+\beta_y]} \quad (3.3)$$

$$\beta_x = -kd_x sin\theta_0 cos\emptyset_0 \quad (3.4)$$

$$\beta_y = -kd_y sin\theta_0 sin\emptyset_0 \quad (3.5)$$

Where β_y,β_x are the progressive phase shifts in the x and y directions, respectively, θ and ϕ is the elevation and azimuth angles, respectively, and λ is the wavelength at the operating frequency

Finally, w_{nm} represents the amplitude and phase excitations of the (n,m) element. For random arrays, the elements are randomly located along the x and y-axes and the interelement spacing is irregular.

Thus, (3.3) can be rewritten as

$$AF(\theta,\emptyset) = \sum_{n=1}^{N}\sum_{m=1}^{M} w_{nm} e^{j\frac{2\pi}{\lambda}[(n-1)(x_{n,m} sin(\theta)\, cos(\emptyset)+\beta_x)+(m-1)(y_{n,m}\, sin(\theta)\, sin(\emptyset)+\beta_y]} \tag{3.6}$$

Where $x_{n,m}$ and $y_{n,m}$ are the random locations of the (n,m) element. From (3.3) and (3.6), it is clear that the total number of the adjustable excitation elements, w_{nm} , is $N \times M$ which is quite large and ,thus, the use of global stochastic optimizations such as genetic algorithms is associated with high complexity and slow convergence. Further, in many cases, the optimal solution may not require such a highly complex and global optimization algorithm since the searching spaces may be convex. Instead, this problem can be solved efficiently by the convex optimization where the unknown array excitations,w_{nm} , constitutes a set of linear functions on a convex space.

The present work develops an innovative methodology for convex optimization problem is formulated as the determination of the excitation amplitudes and phases of the array elements such that the resulting radiation pattern obeys one of the following two constraints:

Constraint 1: Obtaining Feasible Minimum Sidelobe Level for a Given Beam Width

In this case, the convex optimization minimizes the sidelobe level outside the beamwidth of the array pattern and it has a unit sensitivity at target direction to avoid any distortion in the main beam. These constraints are written as follows:

$$|AF(\theta,\emptyset)| \text{ is minimum} \qquad (3.7)$$

$$\text{Subject to } AF\left(\beta_x,\beta_y\right) = 1 \qquad (3.8)$$

$$|AF(\theta_i,\emptyset_i)| \leq SLL \qquad (3.9)$$

$$-90^0 \leq \theta_i \leq -\Omega_{BW} \text{ , and } \quad \Omega_{BW} \leq \theta_i \leq 90^0$$

Where SLL, is the feasible starting value of the sidelobe level in the elevation plane for fixed value of azimuth angle,Ω_{BW} and is the required first null to null beam width in the elevation plane. The constraint in (3.8) aims at preserving the unit gain in the target direction, while the constraint in (3.9) is for obtaining the feasible minimum sidelobe level for a given beam width. The constraint 1 can be seen in figure (3.1)

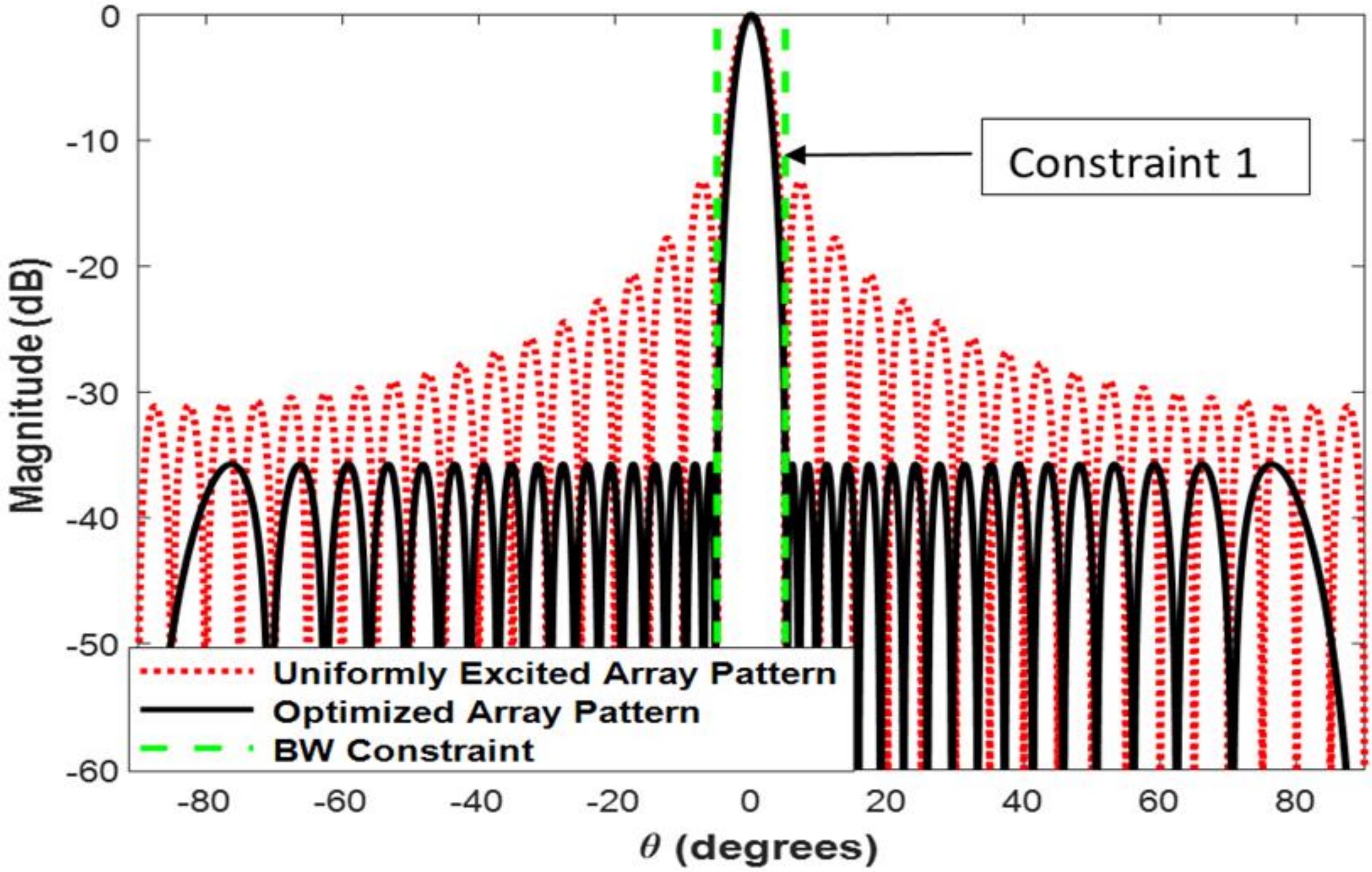


Figure (3.1) :Constraint 1, Obtaining Feasible Minimum Sidelobe Level for a Given Beam Width.

Constraint 2: Obtaining Minimum Beam Width for a Given Sidelobe Level

In this case, the optimized array pattern is designed such that it has unit sensitivity at desired target direction, obeys the constraint on the sidelobe level outside the main beam, and minimizes the beamwidth of the array pattern. The constrain two can be seen in the figure (3.2).The results of applying these two cases are shown in the chapter four.

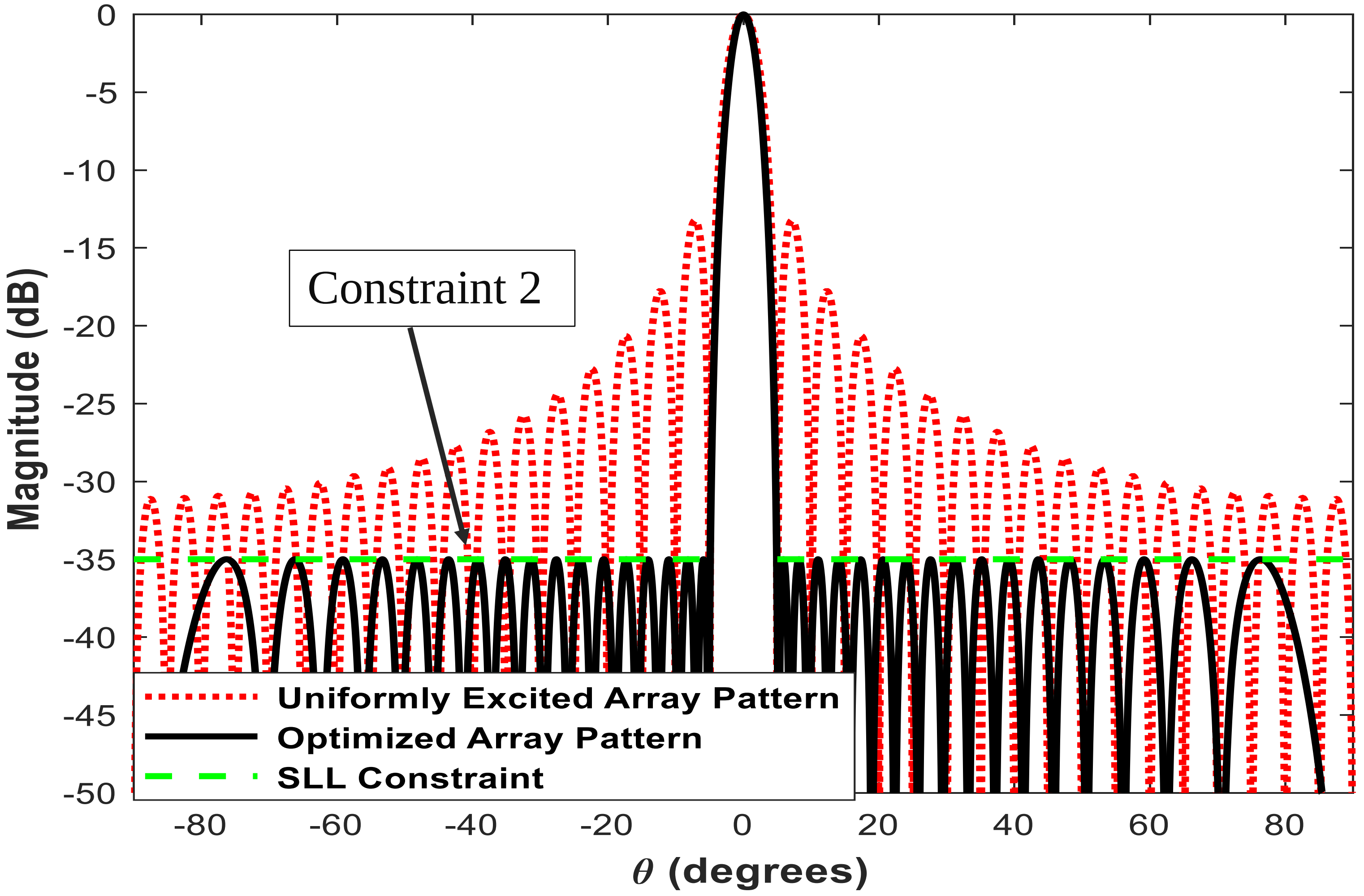


Figure (3.2): Constraint 2, Obtaining Minimum Beam Width for a Given Sidelobe Level.

CHAPTER FOUR

SIMULATION RESULT

The implementation of the convex optimization theories suggested in the previous chapters will be covered here, also with comparisons and comments on the results.

The convex optimization used to optimizing three-antenna array configuration, linear array with uniform inter element space, uniform rectangular planar array and random planar array. The convex optimization problem is formulated as the determination of the excitation amplitudes and phases of the array elements such that the resulting radiation pattern obeys one of the following two constraint the first constraint, which state obtaining feasible minimum sidelobe level for a given beam width ,and the second constraint, which state obtaining minimum beam width for a given sidelobe level .Numerous examples are given and evaluated using simulations in order to evaluate the effectiveness of the provided optimization strategy.

4.1 Obtaining Feasible Minimum Sidelobe Level for a Given Beam Width, with Constant Number of Array Element

In this case, the excitation amplitudes and phases are optimized such that the corresponding array factor complies with the imposed constraints in chapter three according to (3.7), (3.8), and (3.9). Note that the total number of the array elements in all array configurations (linear, planar, and random) was fixed to 36 elements.

In the first, a uniformly spaced linear array having a total number of elements equal to 36 (i.e., N=36 and M=1) that are spaced by $\lambda/2$ is considered (selected an inter-element spacing equal to half a wavelength to prevent grating lobe effects from obscuring the results of the amplitude weighting or tapering [37])

The required first null to null beam width (Ω_{BW}) of the optimized array pattern was chosen to be equal to that of the standard uniformly excited linear array with 36 elements which is 5^0, ($\Omega_{BW} = 5^0$). Note that the FNBW of the optimized array is restricted to be as narrow as that of the standard uniformly excited linear array while solving for feasible minimum sidelobe level. The target direction is assumed to be known and equals to 0^0. Fig (4.1) shows the radiation pattern of the optimized linear array. For comparison purposes, the radiation pattern of the standard uniformly excited linear array is also shown in this figure. The elements locations, optimized excitation amplitudes and phases are shown in Fig (4.2), (4.3) and (4.4).

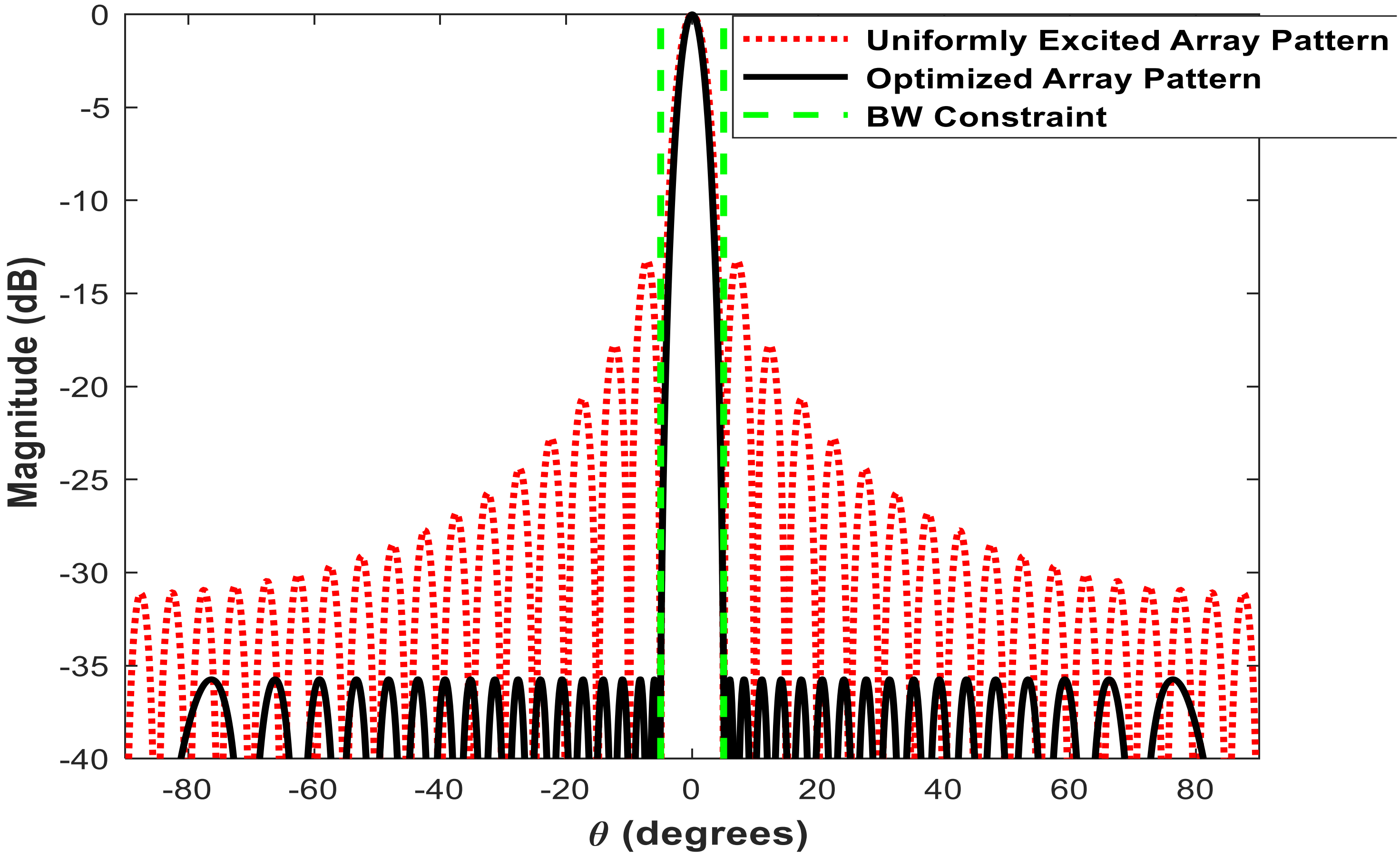


Figure (4.1): The Optimized Radiation Pattern of the Uniformly Spaced Linear Array with 36x1 Elements for $\Omega_{BW}=5^0$.

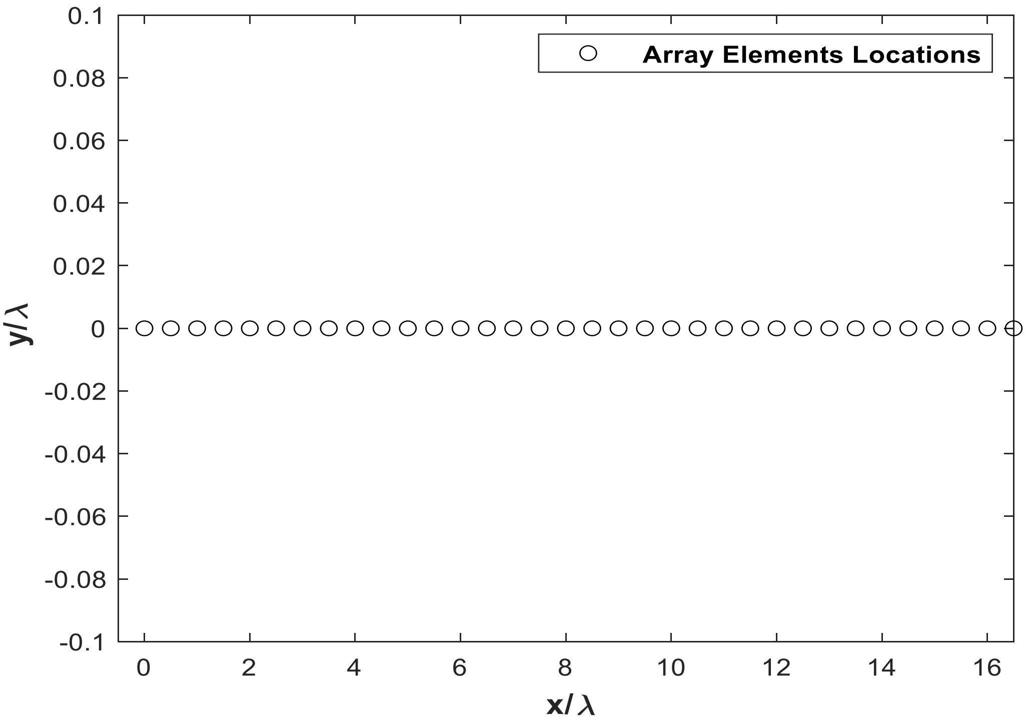


Figure (4.2): Array Elements Locations.

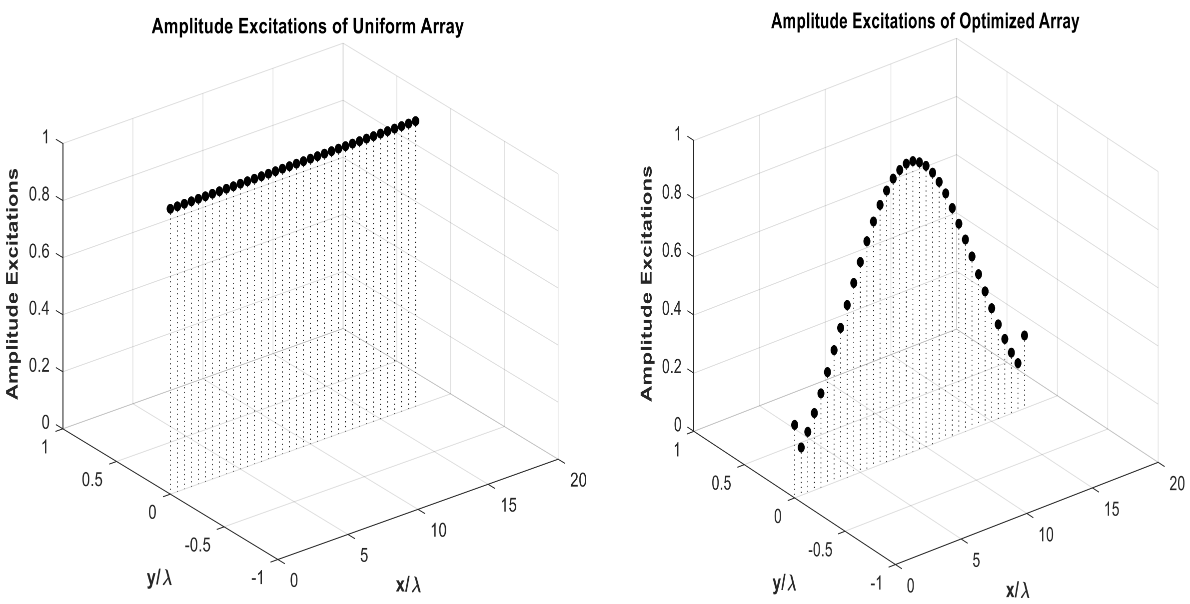


Figure (4.3): Amplitude Excitation of Uniform and Optimized Array.

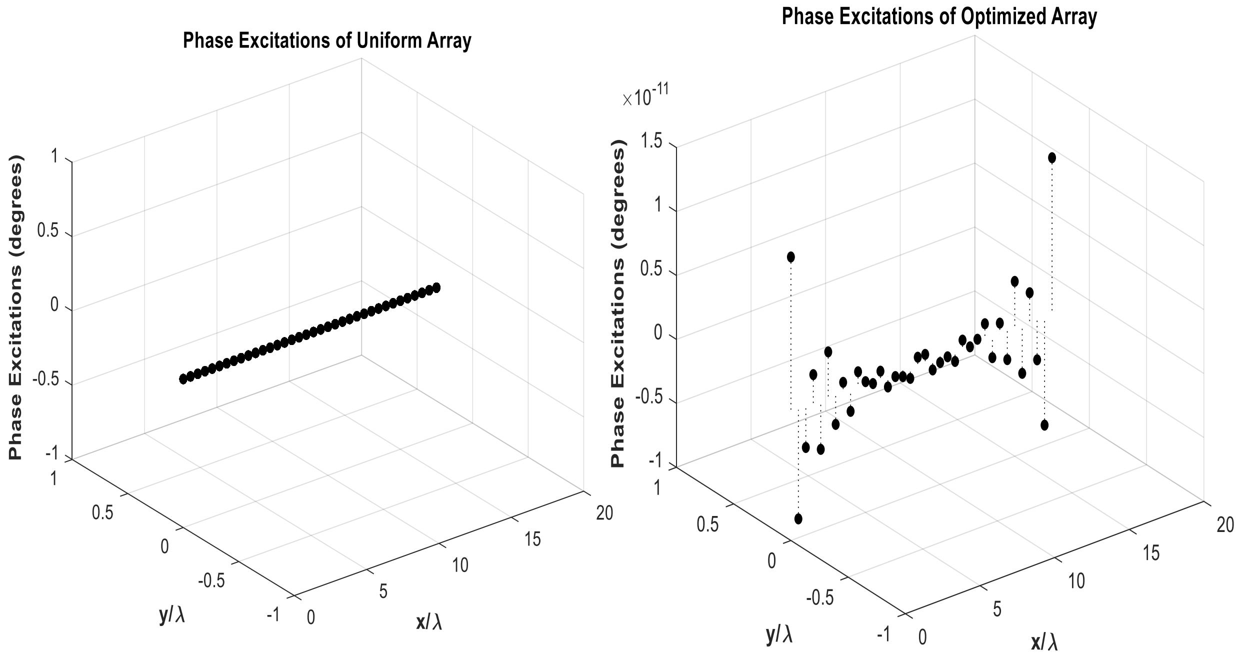


Figure (4.4): Phase Excitation of Uniform and Optimized Array .

In the figure (4.1) the optimization radiation pattern of the uniformly spaced linear array satisfy the constraint one, obtaining feasible minimum sidelobe level for a given beam width, perfectly when obtain the minimum SLL equal to (-35.74dB) in comparison with (-13.2dB) and directivity equal to (34.363 dB) which is higher than (32.2524 dB) ,directivity of standard uniformly excited linear array with 36 elements ,with fixed HPBW .

From figure (4.2) ,it can be seen that the array element location along line with uniform space $d = \lambda/2$ which mean L=17.5(L is the overall length of the array) [38].The array element location can be implement easy for this situation.

In the second, a uniformly spaced planar array with $N \times M = 6 \times 6$ elements is considered again, the same optimization constraints as in the previous example was imposed to obtain the feasible minimum sidelobe level for a given narrow beam width, $\Omega_{BW} = 5^0$. The pattern of the optimized planar array shown in Figure (4.5)

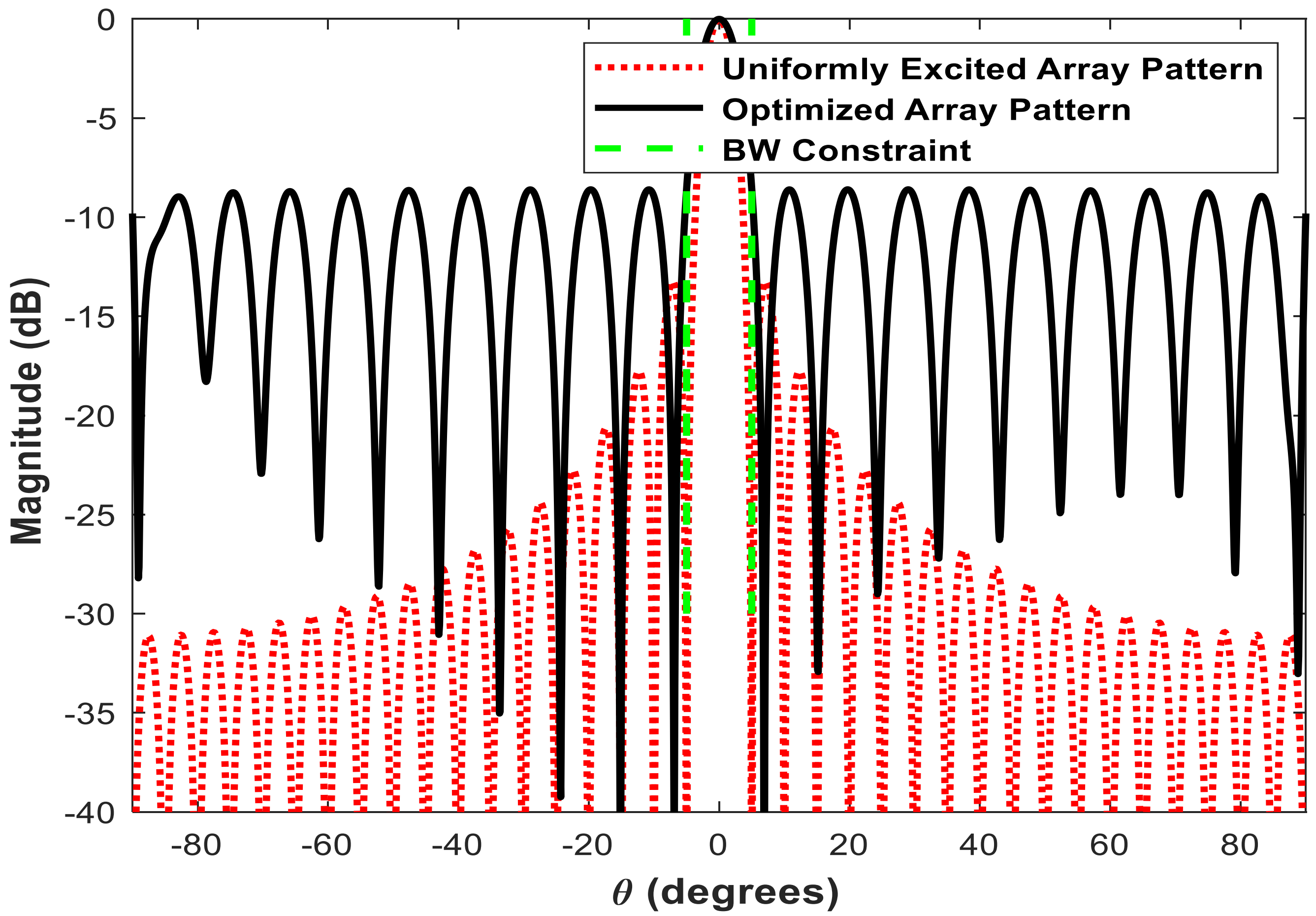


Figure (4.5): The Pattern of the Optimized Planar Array with 6x6 Elements for $\Omega_{BW} = 5^0$.

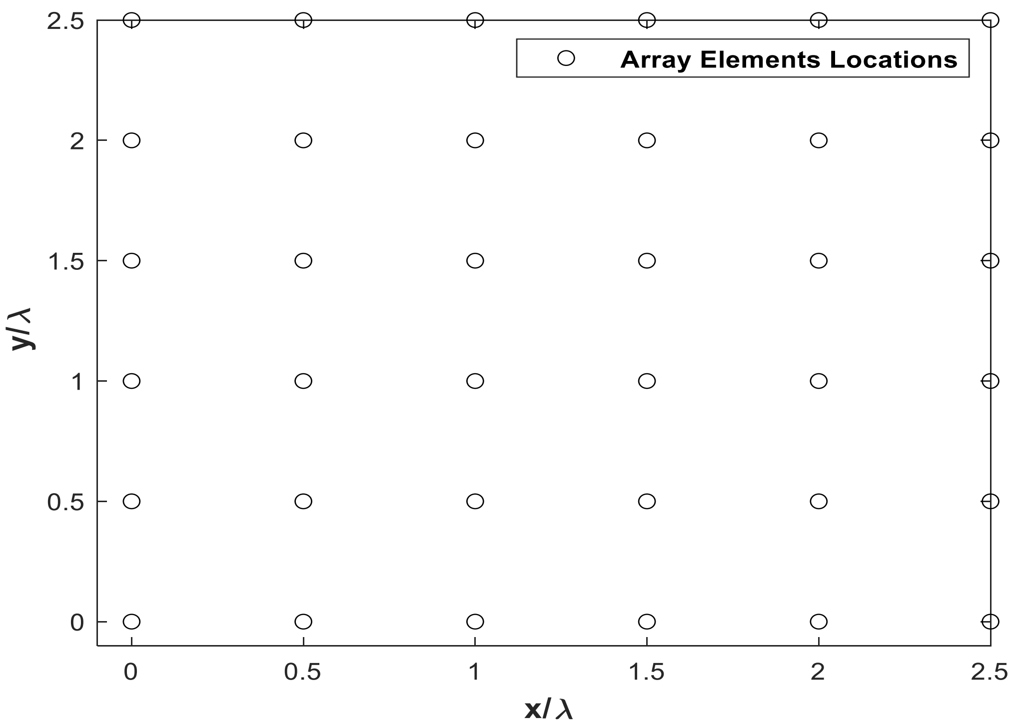


Figure (4.6): Array Element Location of Optimized Planar Array.

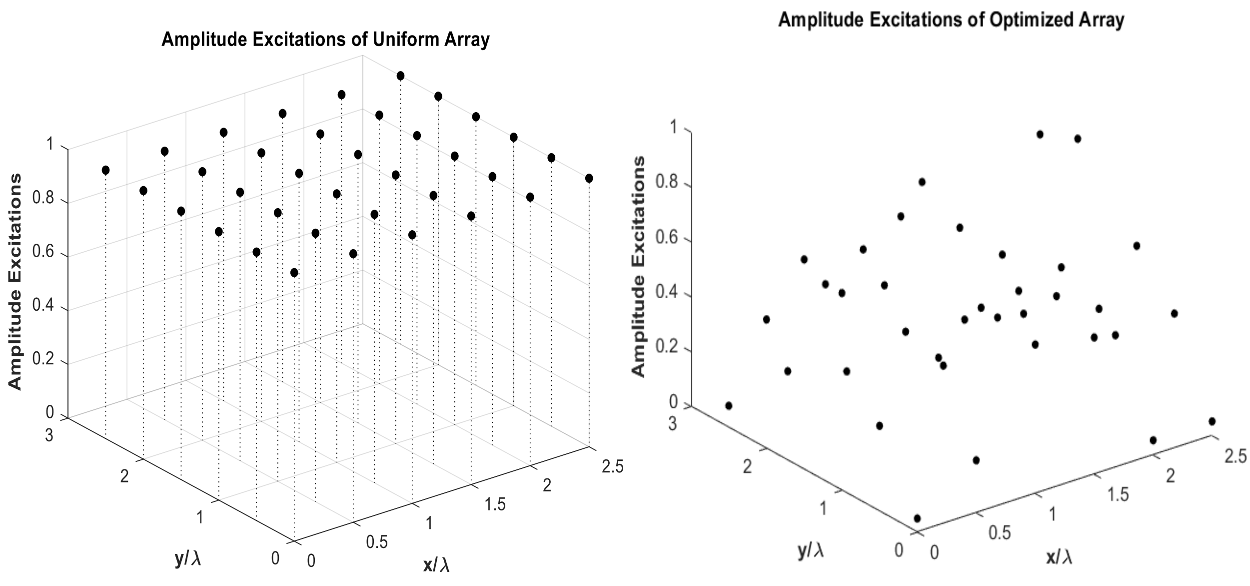


Figure (4.7): Amplitude Excitation of Uniform and Optimized Uniform Planar Array with 6x6 Elements for $\Omega_{BW} = 5^0$.

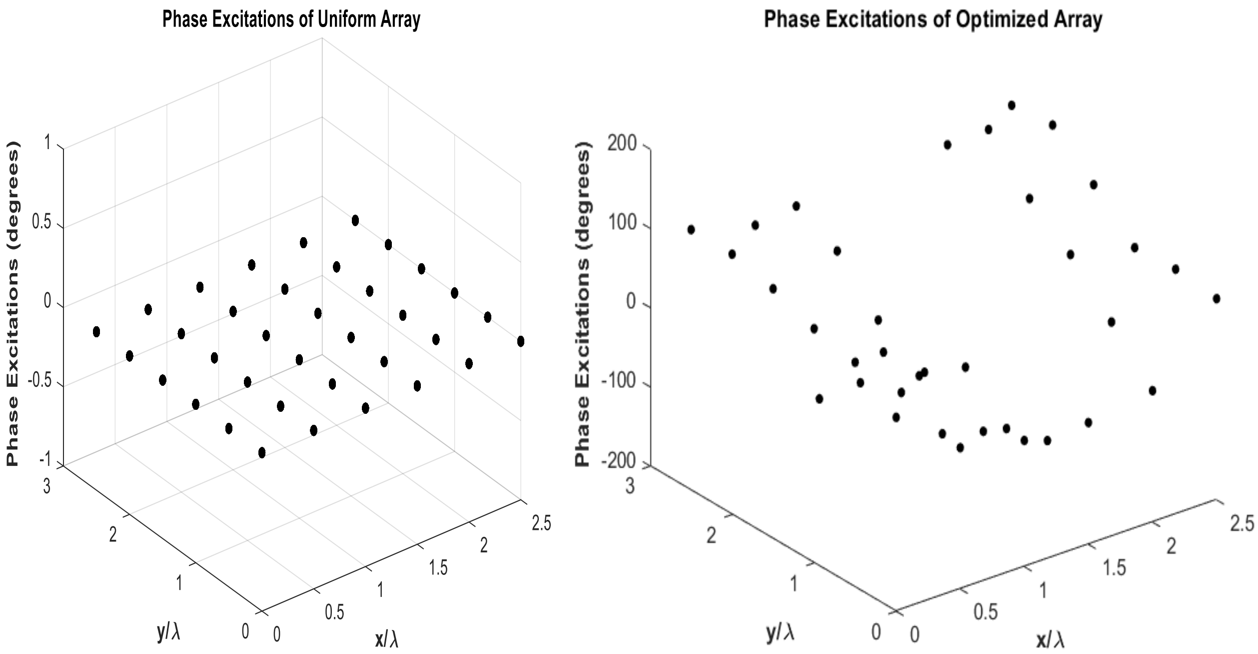


Figure (4.8): Phase Excitation of Uniform and Optimized Uniform Planar Array with 6x6 Elements for $\Omega_{BW} = 5^0$.

It can be seen from the figure (4.5), the pattern of the optimized planar array with 6x6 elements for ($\Omega_{BW} = 5^0$), and from the MATLAB code result the SLL equal (-8.59 dB) which is higher than that of the standard uniformly excited linear array, -13.2 dB. The directivity equal to (23.526) which is lower than of the standard uniformly excited linear array, (32.2524 dB), because of the space between elements chosen to be fixed to ($\lambda/2$) which means that aperture of the uniform planar array is lower than the optimized linear array in first step.

The planar array element distribution uniformly on rectangular with (2.5×2.5) can see the elements location in figure (4.5).

In the third, a randomly spaced planar array with also N × M = 6 × 6 elements is considered. Again, the beam width constraint was $\Omega_{BW} = 5^0$ as in the previous examples. The results for the optimized random array are shown in Fig4.9. From this figure, it can be seen that the feasible minimum sidelobe level was -7.7 dB, which is also higher than that of the standard uniformly excited linear array, -13.2 dB.

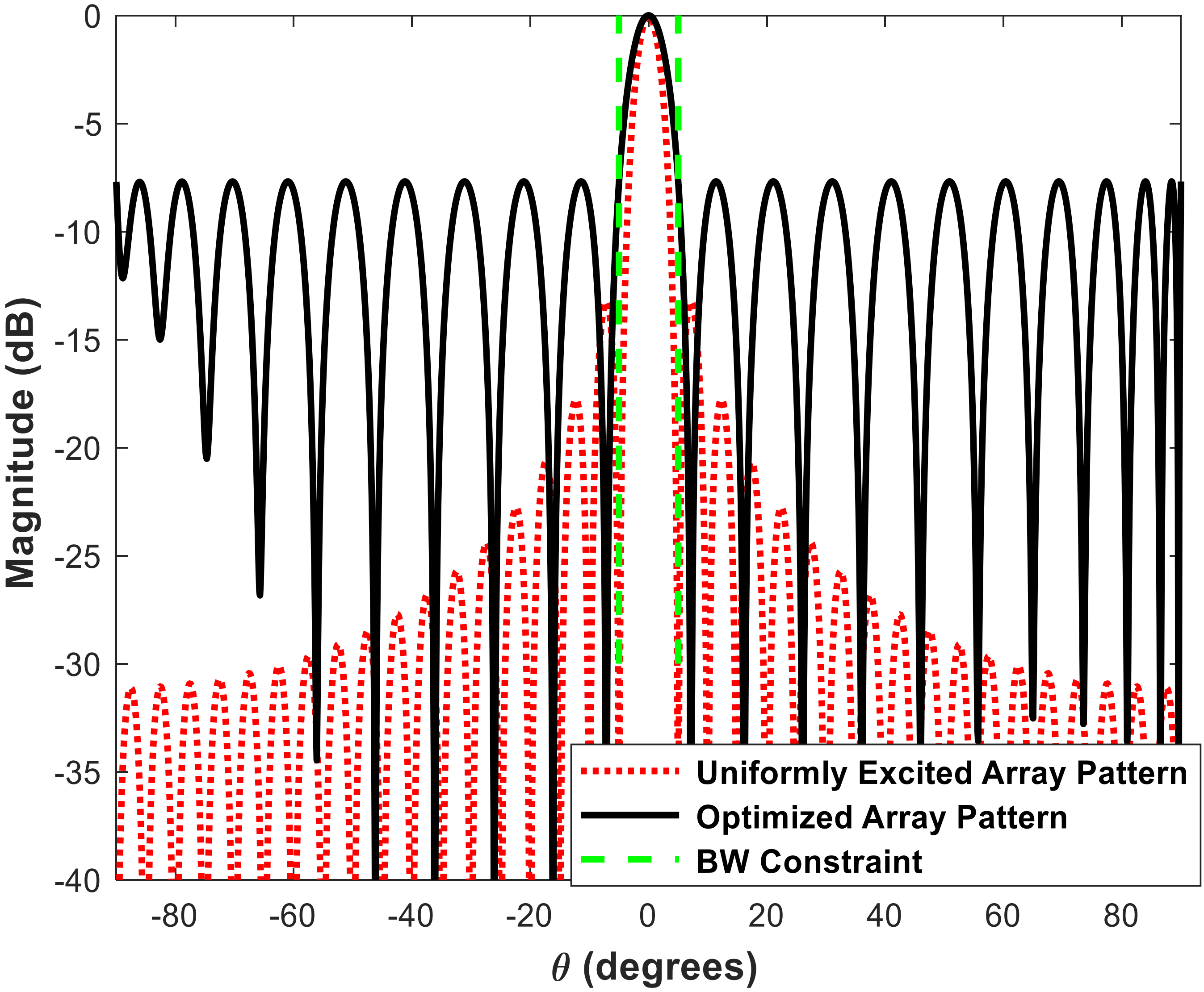


Figure (4.9): The Pattern of the Optimized Random Planar Array with N=36 and $\Omega_{BW}=5^0$.

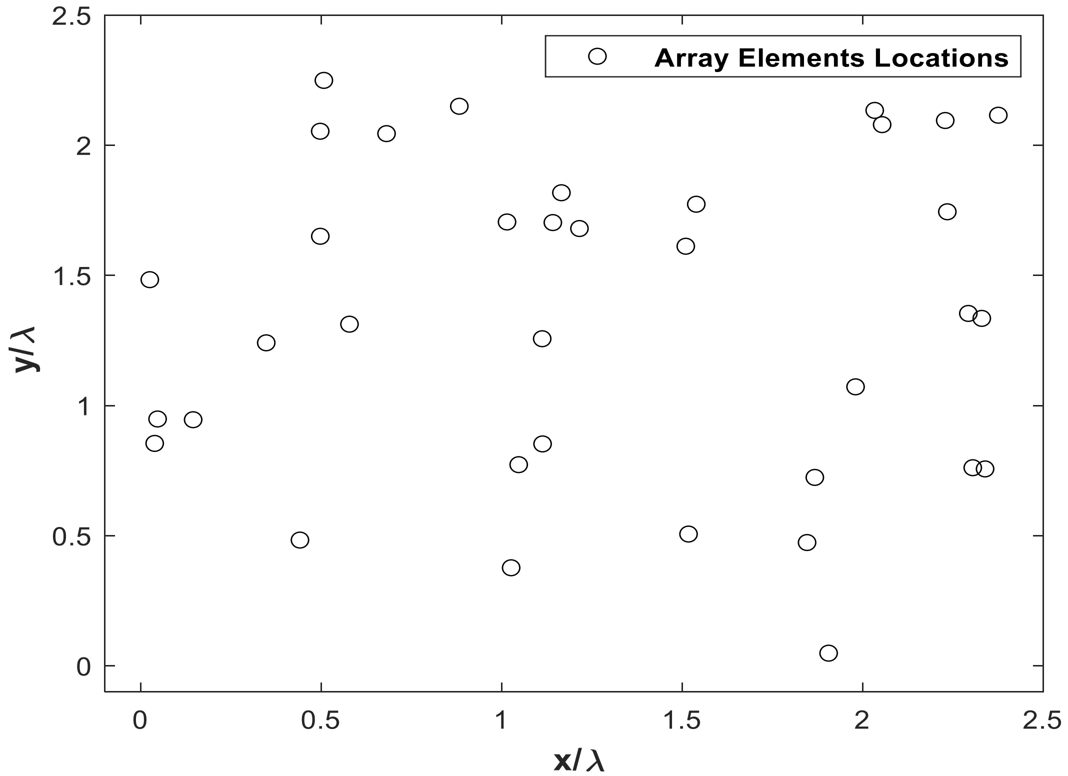


Figure (4.10): Random Planar Array Element Location with 6x6 Elements for $\Omega_{BW} = 5^0$.

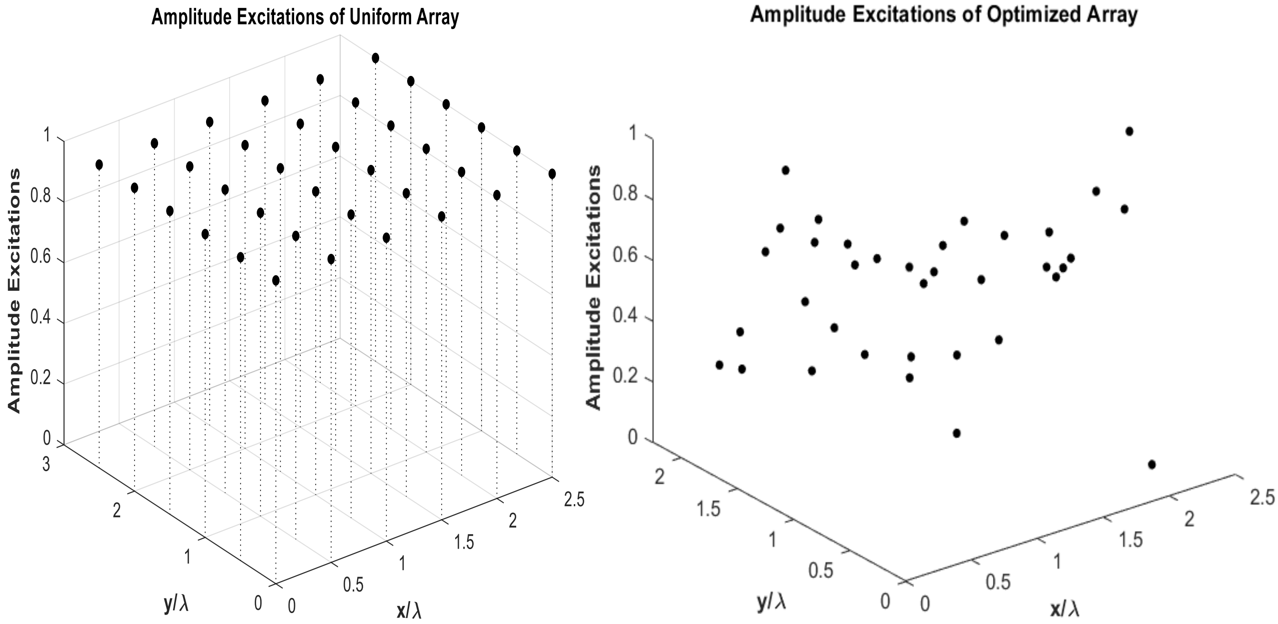


Figure (4.11): Amplitude Excitation of Uniform and Optimized Random Planar Array with 6x6 Elements for $\Omega_{BW} = 5^0$.

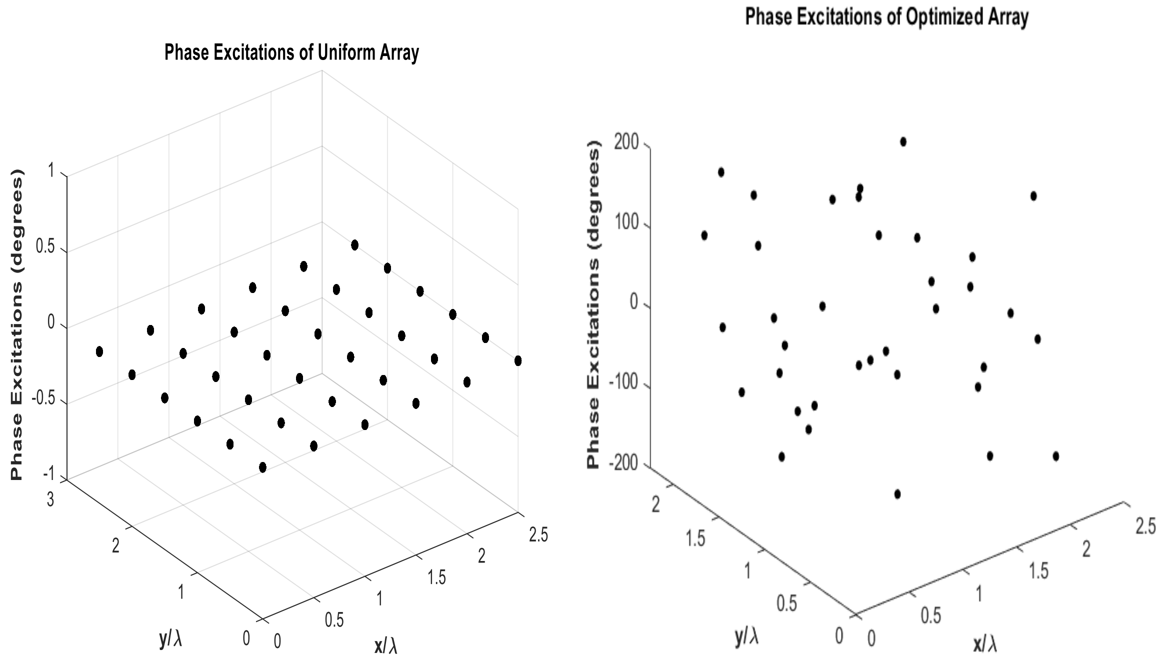


Figure (4.12): Phase Excitation of Uniform and Optimized Random Planar Array with N=36 Elements for $\Omega_{BW} = 5^0$.

4.2 Obtaining Feasible Minimum Sidelobe Level for a Varied Beam Width, from $\Omega_{BW} = 3^0$ up to $\Omega_{BW} = 20^0$

Nevertheless, much lower SLL can be obtained for wider beam width for this reason the beam width was varied from $\Omega_{BW} = 3^0$ up to $\Omega_{BW} = 20^0$, all theories for the previous case are still valid, and the corresponding feasible minimum SLL and the directivities of the three array configurations was recorded in three table (4.1),(4.2)and (4.3). For these values of beam widths, the directivities of the three array configurations were plotted as shown in Figure(4.13) and feasible minimum SLL of the three array configurations were also plotted as shown in Figure(4.14) .

Table (4.1) Optimized Uniform Linear Array with N=36 and $d = {}^{\lambda}/_{2}$.

Ω_{BW} (degree)	SLL (dB)	Directivity of optimized array (dB)
2^0	-10.84	29.373
4^0	-27.37	35.2
5^0	-35.74	34.363
6^0	-44.13	33.545
8^0	-60.99	32.244
10^0	-77.96	31.258
12^0	-95.09	30.469
14^0	-112.4	29.817
16^0	-129.91	29.266
18^0	-147.39	28.7886
20^0	-163.4	28.3556

Table (4.2) Optimized Uniform Planar Array with N*M=36 and $dy = dx = \lambda/2$

ΩBW (deg)	SLL (dB)	Directivity of optimized array (dB)
2^0	-1.86	14.306
4^0	-6.63	21.71
5^0	-8.59	23.526
6^0	-11.12	25.517
8^0	-18.74	27.565
10^0	-25.68	27.161
12^0	-32.08	26.407
14^0	-37.52	25.631
16^0	-43.75	25.021
18^0	-50.68	24.507
20^0	-53.75	23.817

Table (4.3) Optimized Random Planar Array with N=36

Ω_{BW} (deg)	SLL(dB)	Directivity of optimized array (dB)
2^0	-1.38	13.515
4^0	-5.34	19.683
5^0	-7.68	22.406
6^0	-9.88	24.258
8^0	-15.42	26.344
10^0	-21.18	26.463
12^0	-26.41	25.715
14^0	-31.34	25.006
16^0	-34.72	24.205
18^0	-41.28	23.790
20^0	-49.20	23.501

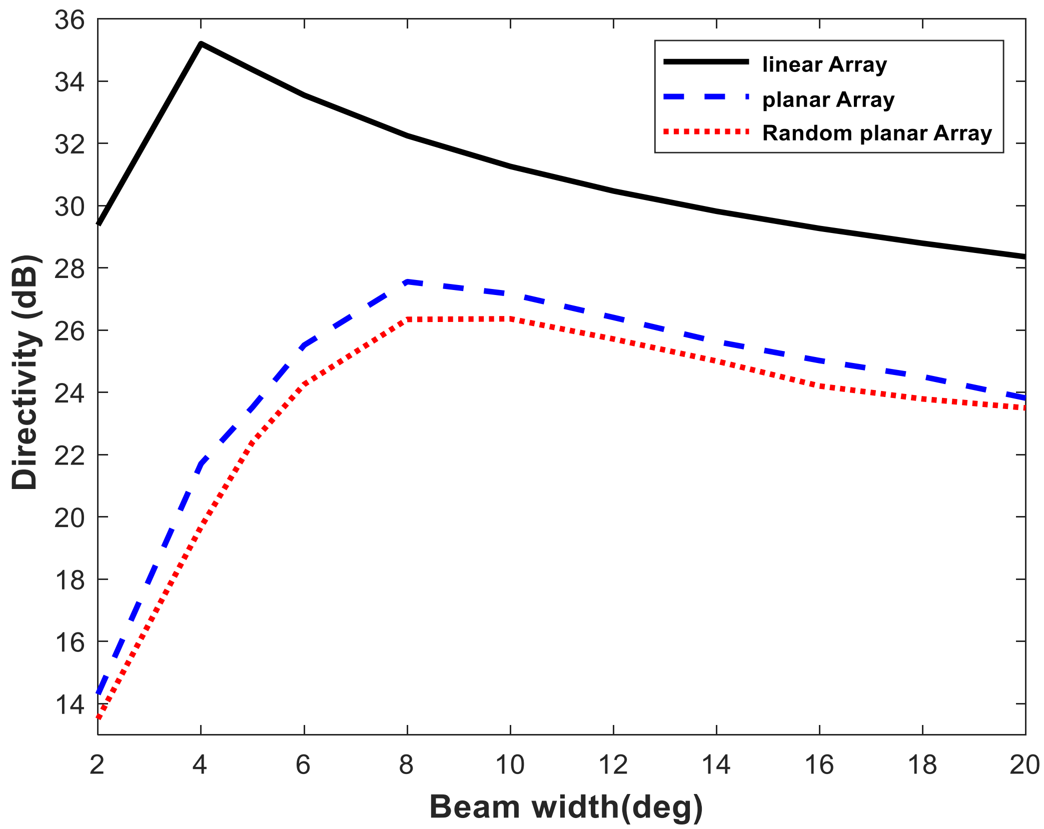


Figure (4.13): Variation of Directivity (dB) Versus Given Beam Width

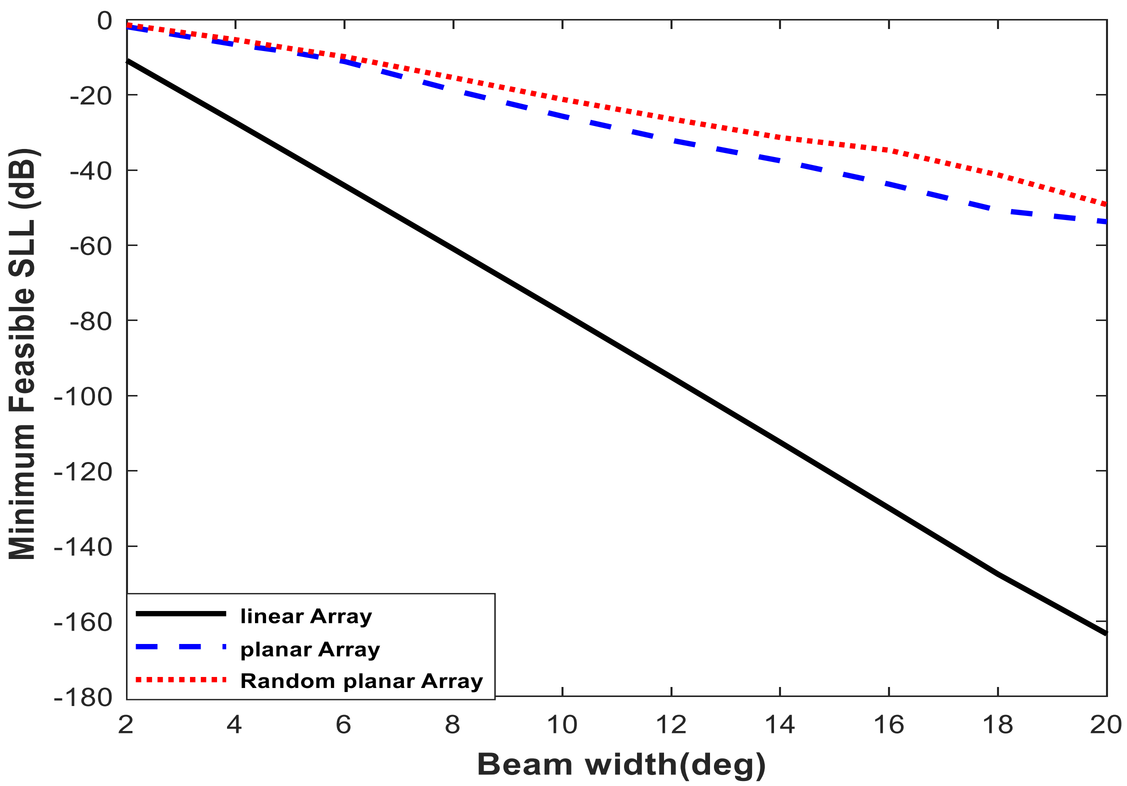


Figure (4.14): Variation of Feasible Minimum SLL Versus Given Beam Width

From these two figures and three tables it can be seen that the linear array gives the feasible minimum SLL and higher directivity. This is mainly because the linear array configuration has wider space diversity than the planar and random arrays, thus, narrower beam width and better directivity can be obtained. Moreover, the feasible minimum SLL can be significantly reduced with an increase in the given beam width value.

4.3Obtaining Feasible Minimum Sidelobe Level for a Given Beam Width, with Varied Number of Array Element

Firstly, a uniformly spaced linear array changing a total number of elements from 36 to 49 (i.e., N=49 and M=1) that are spaced by $\lambda/2$ is considered .The required first null to null beam width (FNBW) of the optimized array pattern was chosen to be equal to that of the standard uniformly excited linear array with 49 elements which is equal to 3.7^0, (Ω_{BW} =3.7^0). When optimizing for a feasible minimum sidelobe level, it should be noted that the FNBW of the optimized array is constrained to be as narrow as that of the standard uniformly excited linear array. The target direction is considered to be known and equal to 0^0.In this case, the excitation amplitudes and phases are optimized such that the corresponding array factor with constraint one, Obtaining feasible minimum sidelobe level for a given beam width, its methodology in chapter three in (3.7),(3.8) and (3.9).Figure (4.15) shows the radiation pattern of the optimized linear array.

For comparison purposes, the radiation pattern of the standard uniformly excited linear array also shown in these figures. From this figure, it is found that the FNBW of the optimized array is exactly equal to that of the standard uniformly excited linear array and the feasible minimum sidelobe level was (–37.46dB) which is much lower than that of the standard uniformly excited linear array, -13.2 dB and the lower than optimized uniform linear array with number of element equal to 36 . The directivity is become more higher than the optimized uniform linear array with number of element equal to 36 ,which is varied from (34.363dB) to(36.907 dB).

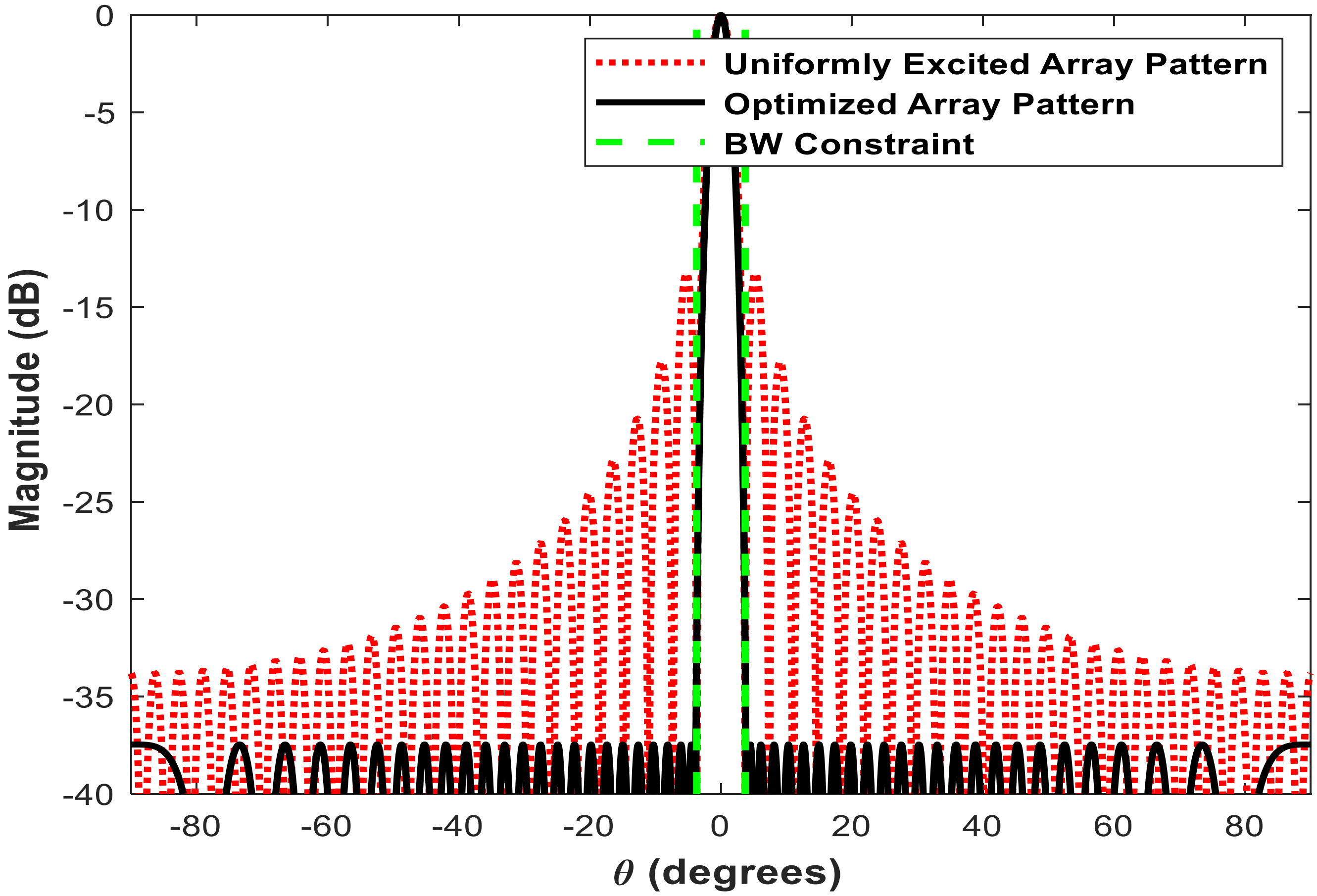


Figure (4.15) The Optimized Radiation Pattern of the Uniformly Spaced Linear Array with 49x1 Elements for $\Omega_{BW}=3.7^0$.

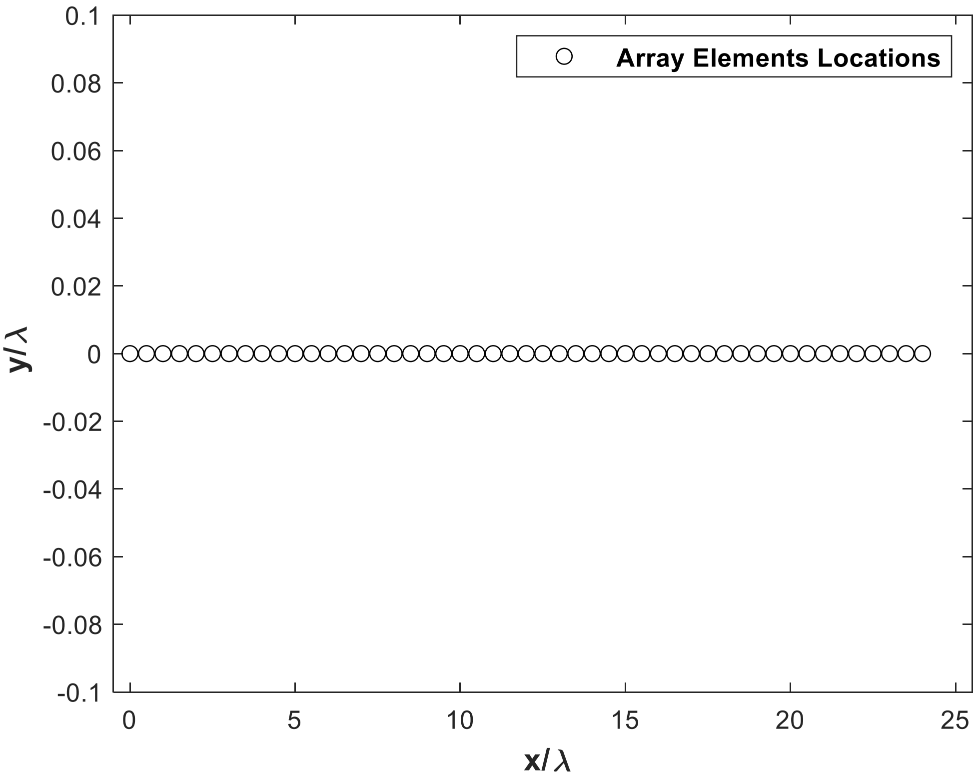


Figure (4.16): Array Element Location of Optimized linear Array 49×1 Element.

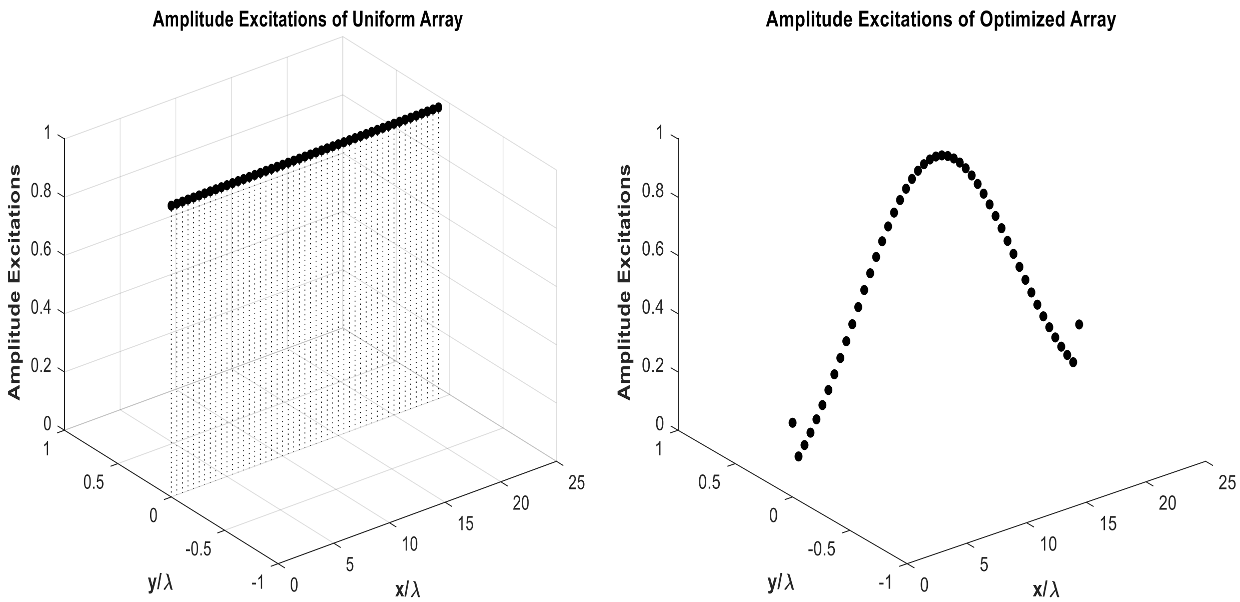


Figure (4.17): Amplitude Excitation of Uniform and Optimized linear Array with 49×1 Elements for $\Omega_{BW}=3.7^0$.

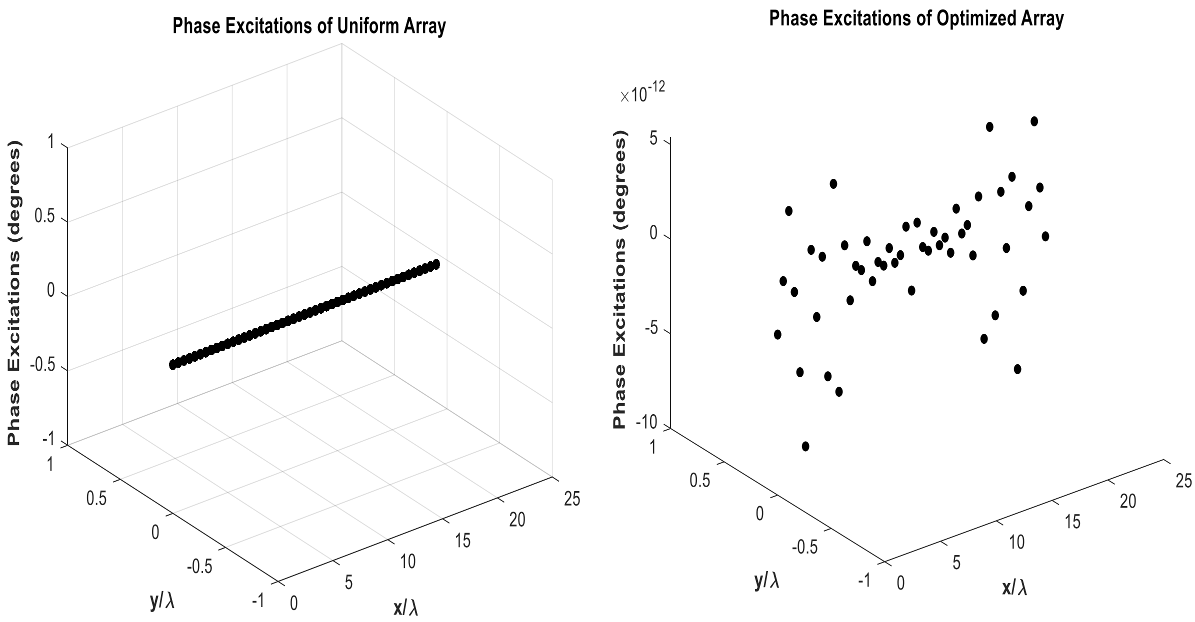


Figure (4.18): Phase Excitation of Uniform and Optimized Linear Array with 49×1 Elements for $\Omega_{BW}=3.7^0$.

The second case for linear optimized array changing the array element number only to become N=64, M=1 and the FNBW become ($\Omega_{BW}=2.84^0$), that is equal to the uniform linear array FNBW. The figures (4.19),(4.20),(4.21) and (4.22) shown the results for this case.

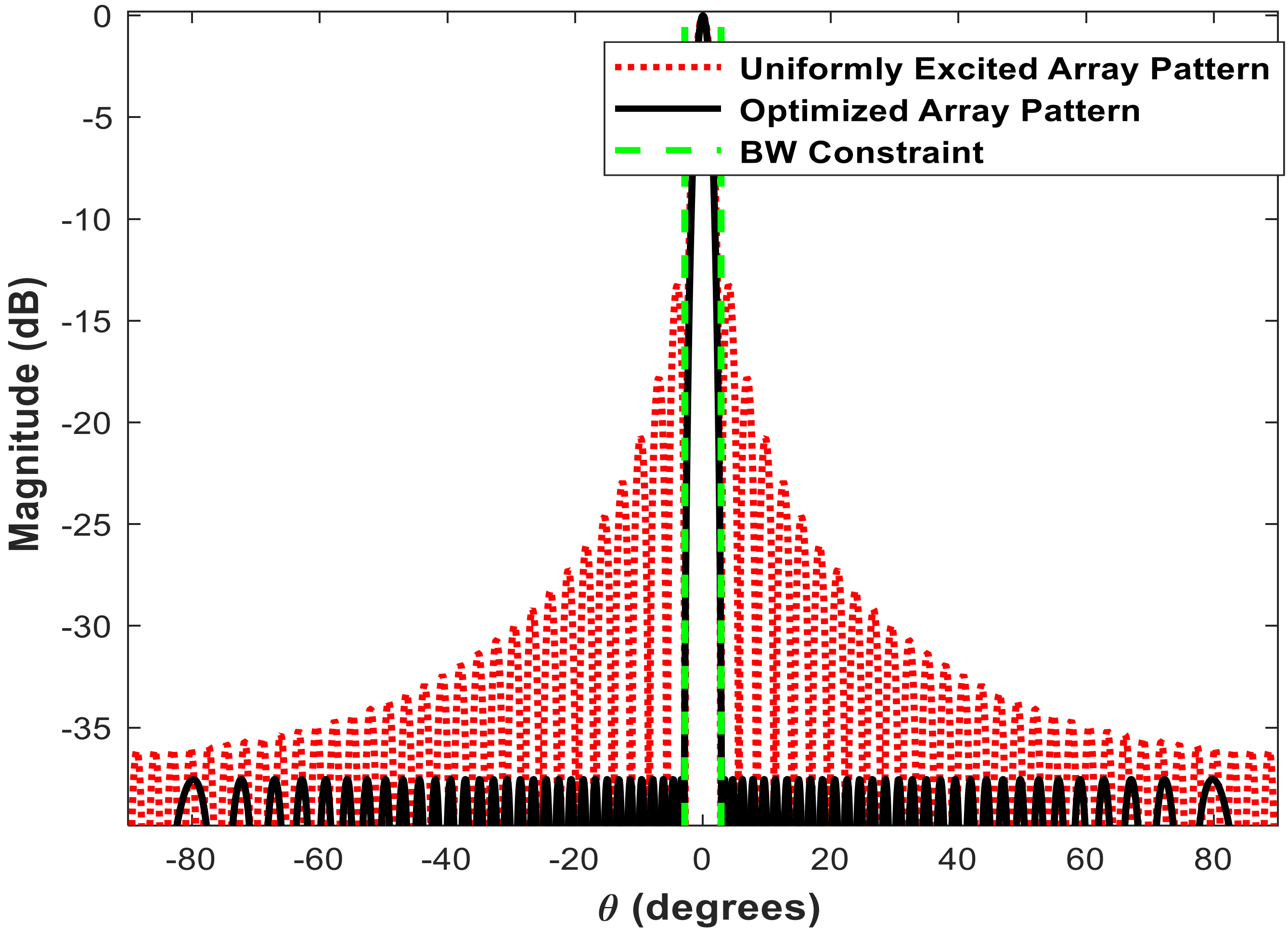


Figure (4.19): The Optimized Radiation Pattern of the Uniformly Spaced Linear Array with 64x1 Elements for $\Omega_{BW}=2.84^0$.

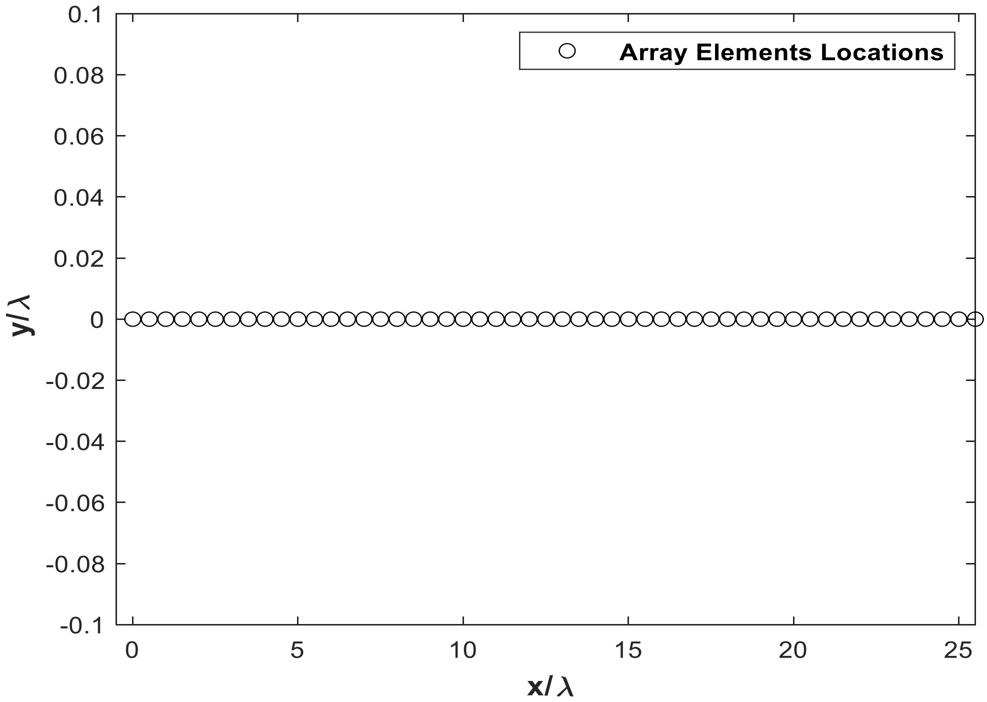


Figure (4.20): Array Element Location of Optimized Linear Array 64×1 Element.

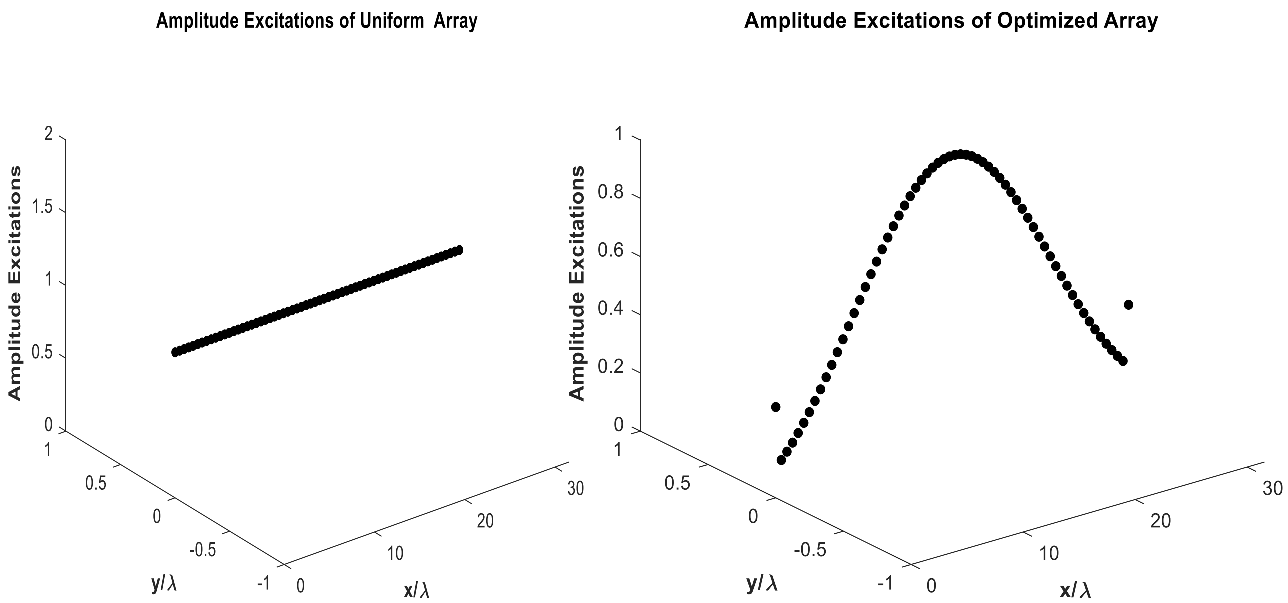


Figure (4.21): Amplitude Excitation of Uniform and Optimized Linear Array with 64×1 Elements for $\Omega_{BW}=2.84^0$.

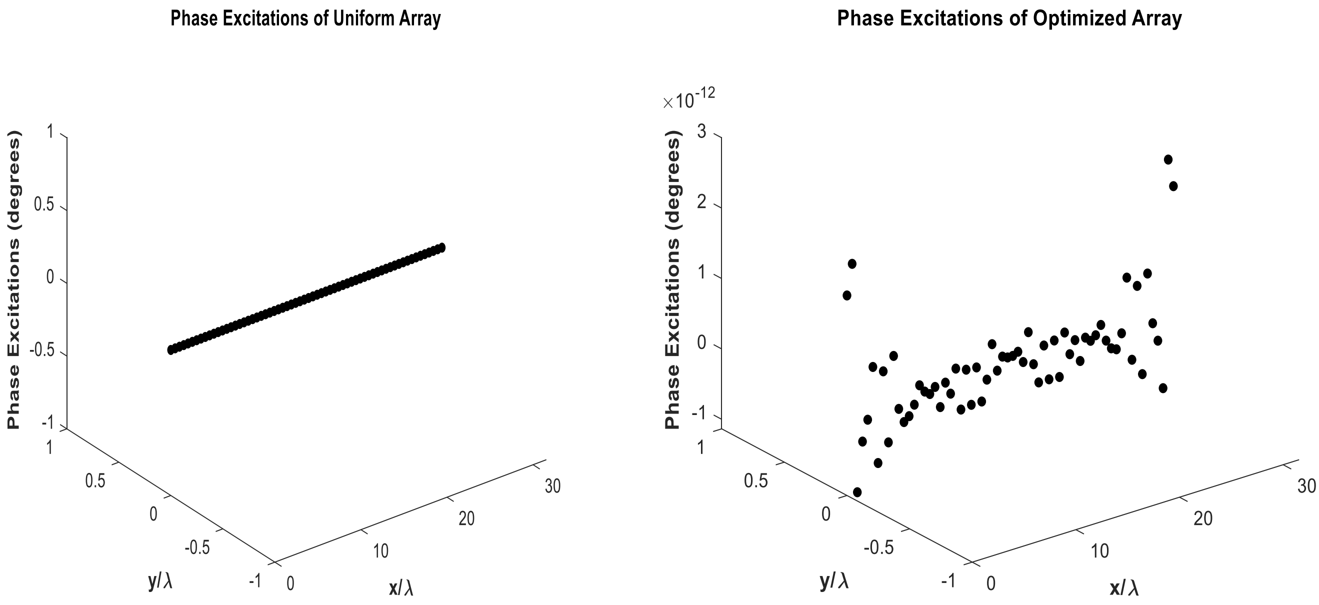


Figure (4.22): Phase Excitation of Uniform and Optimized linear Array with 64×1 Elements for $\Omega_{BW}=2.84^0$.

- For uniform planar array the first case changing the array elements to N=7,M=7 and $\Omega_{BW}=3.7^0$ the results for this case are shown in figures from (4.23) to (4.26)

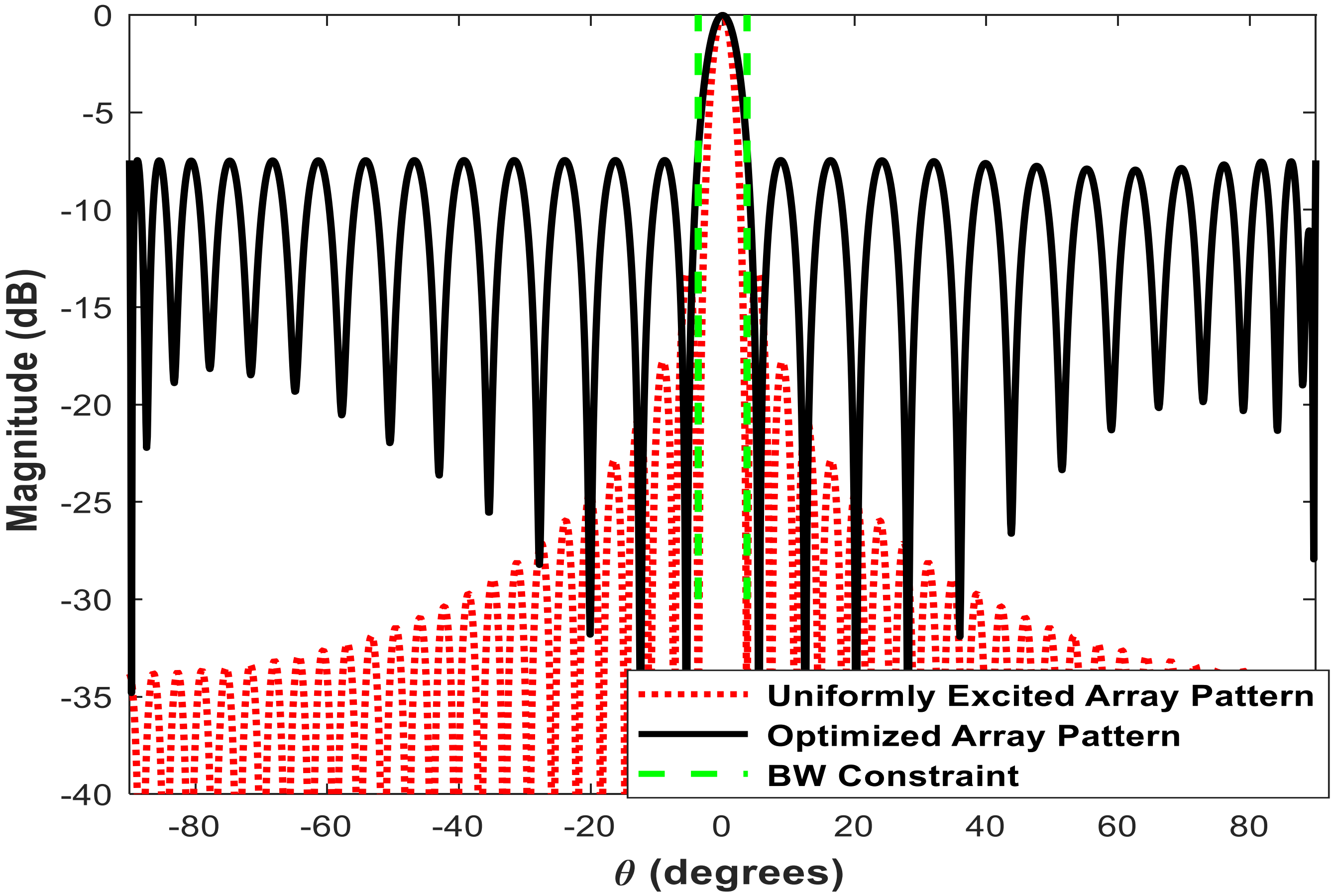


Figure (4.23): The Optimized Radiation Pattern of Planar Uniform Array N×M=49 Element and $\Omega_{BW}=3.7^0$.

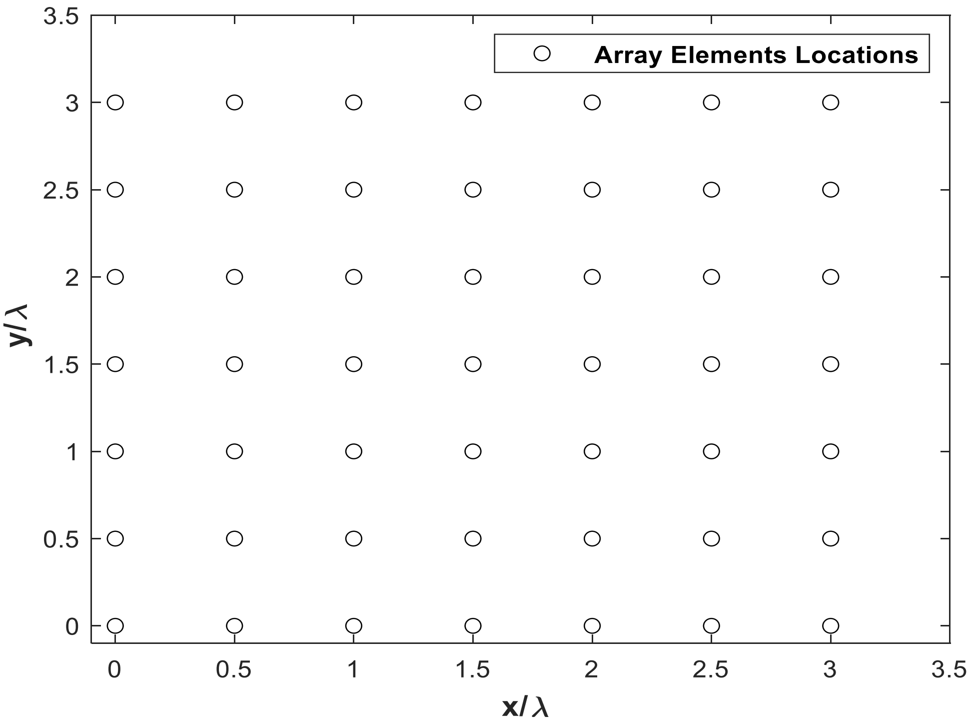


Figure (4.24): Array Element Location of Optimized Uniform Planar Array 7×7 Element.

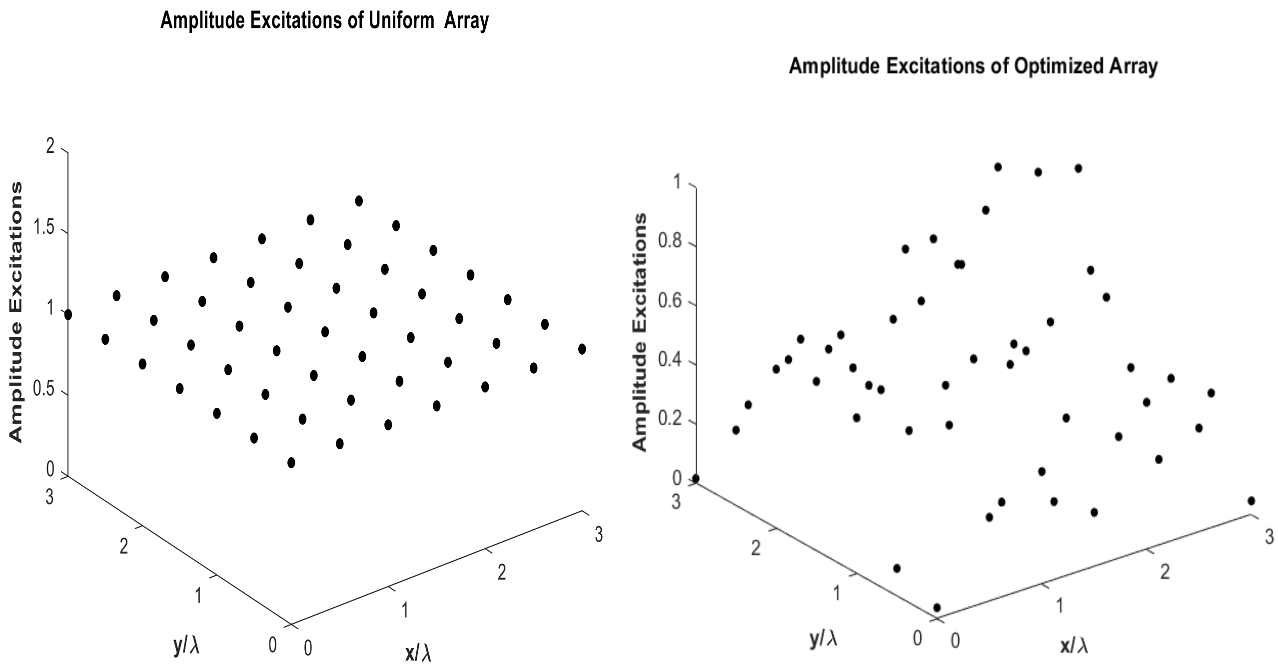


Figure (4.25): Amplitude Excitation of Uniform and Optimized Planar Array with 7×7 Elements for Ω_{BW}=3.7^0.

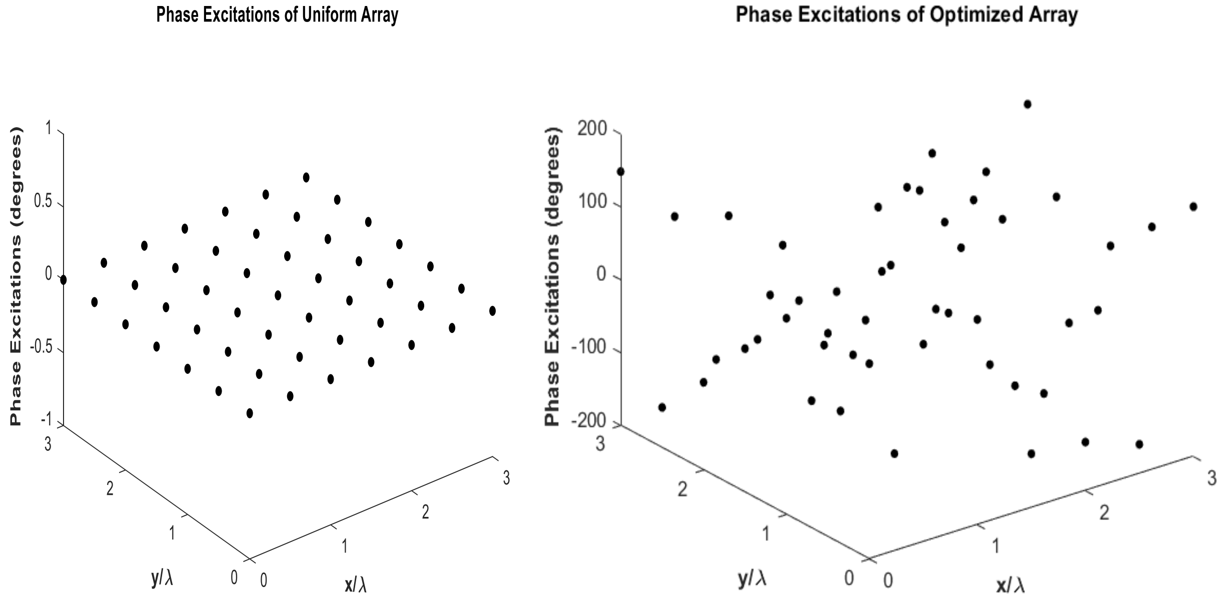


Figure (4.26): Phase Excitation of Uniform and Optimized Planar Array with 7×7 Elements for $\Omega_{BW}=3.7^0$.

- For uniform planar array in second case changing the elements number to N=8,M=8 and Ω_{BW}=2.840 and the results shown in figures from(4.27) to (4.30).

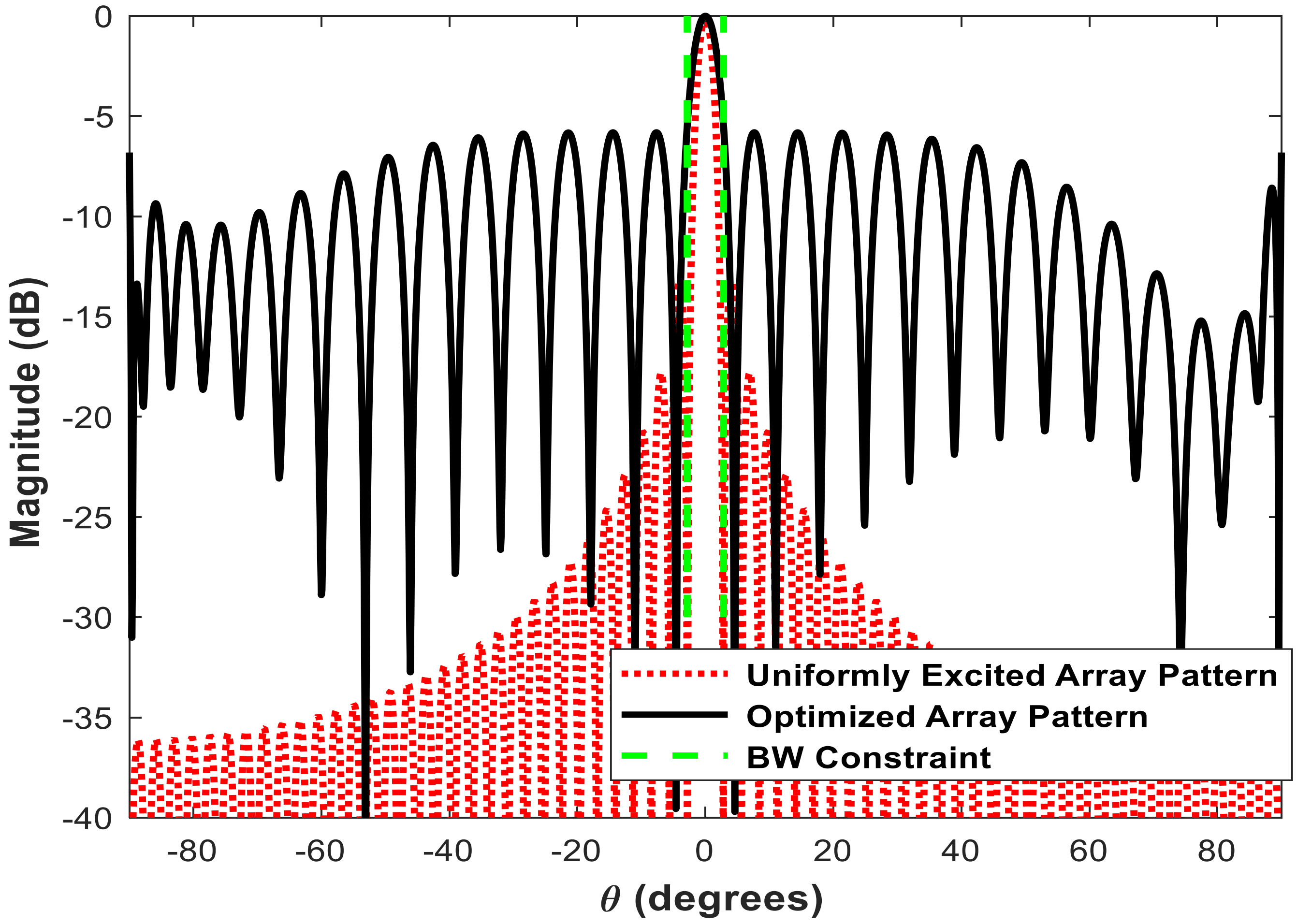


Figure (4.27):The Optimized Radiation Pattern of the Uniformly Spaced Planar Array with 8×8 Element for Ω_{BW}=2.84^{0}.

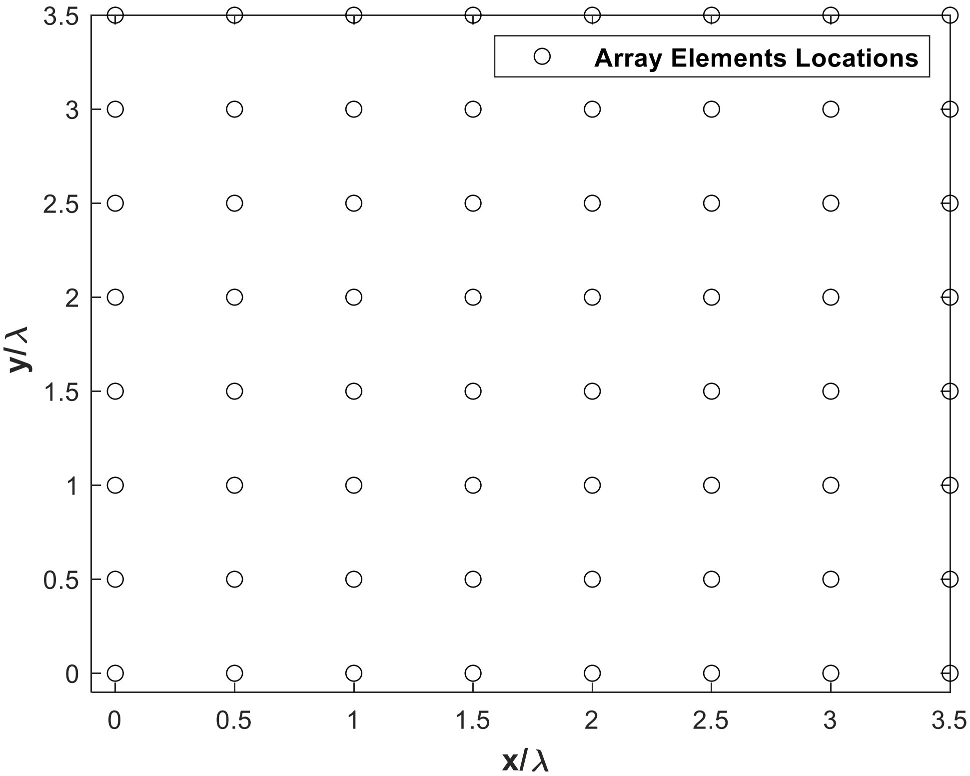


Figure (4.28): Array Element Location of Optimized Uniform Planar Array 8×8 Element.

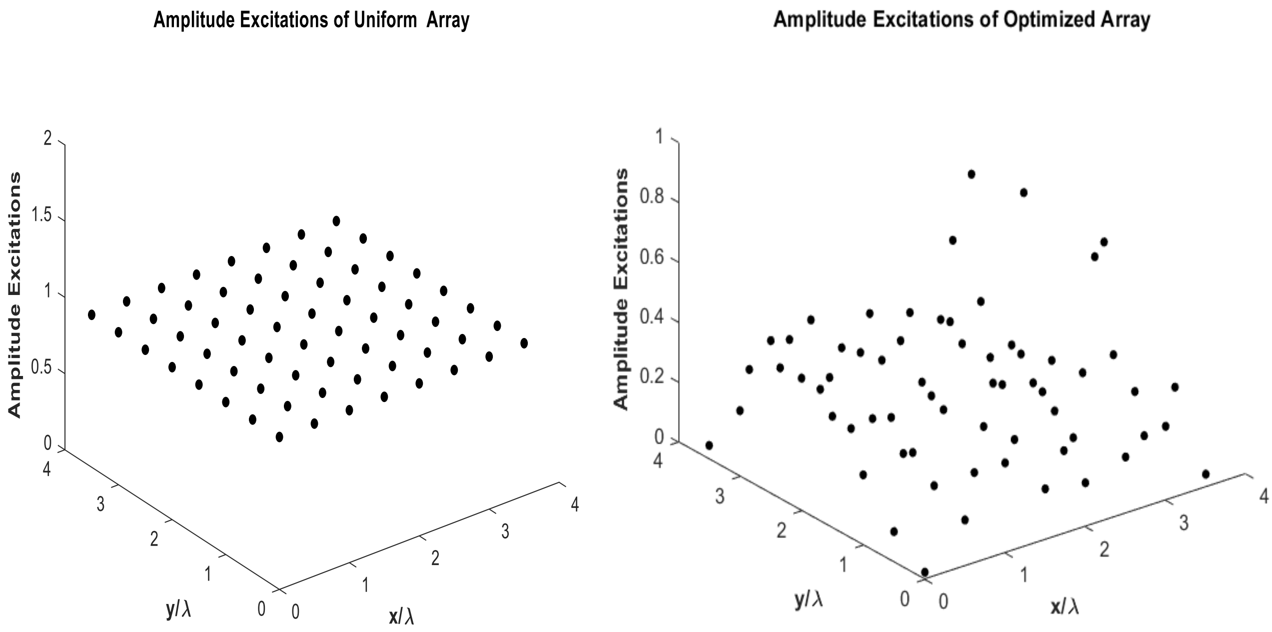


Figure (4.29):Amplitude Excitation of Uniform and Optimized Planar Array with 8×8 Elements for $\Omega_{BW}=3.7^0$.

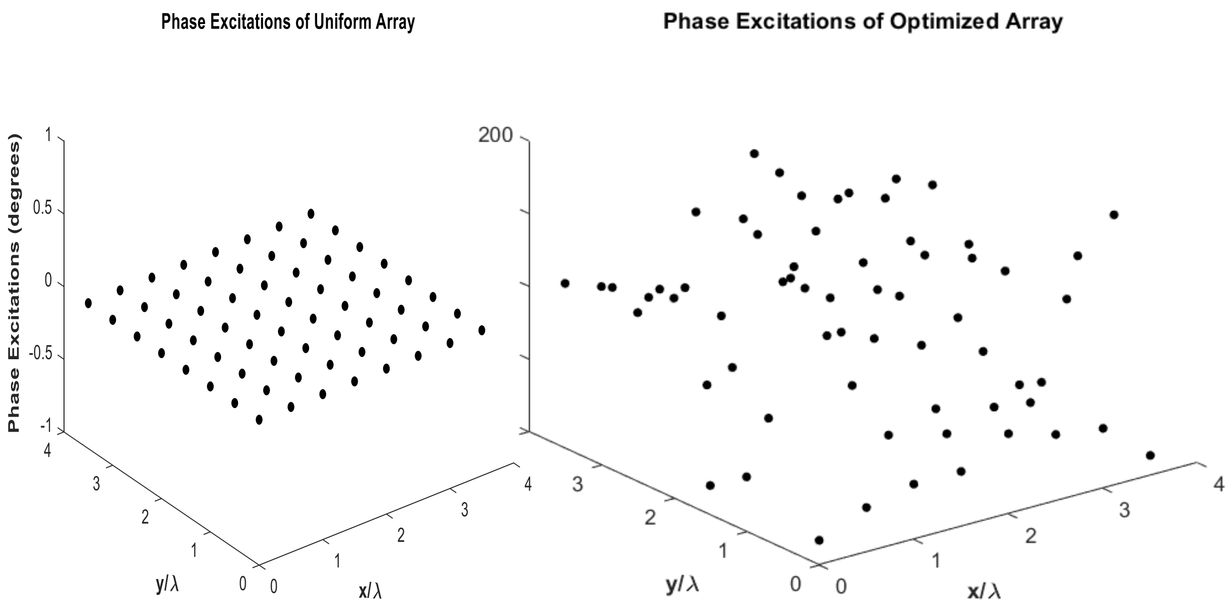


Figure (4.30): Phase Excitation of Uniform and Optimized Planar Array with 8×8 Elements for $\Omega_{BW}=2.84^0$.

- For Random planar array the first case changing the array elements to N=49 and $\Omega_{BW}=3.7^0$ the results for this case shown in figures from (4.31) to (4.34).

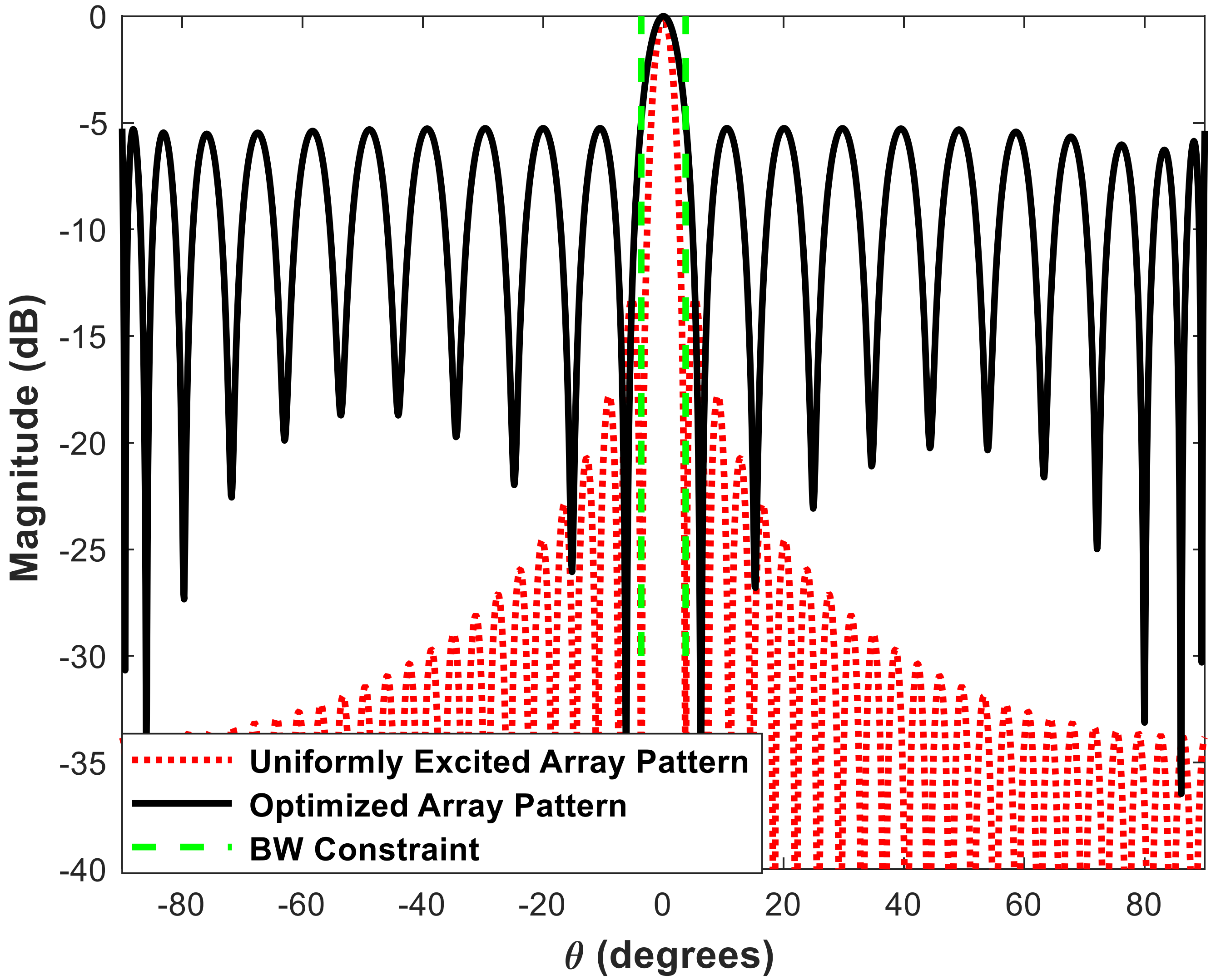


Figure (4.31): The Optimized Radiation Pattern of the Random Planar Array with N=49 Element for $\Omega_{BW}=3.7^0$.

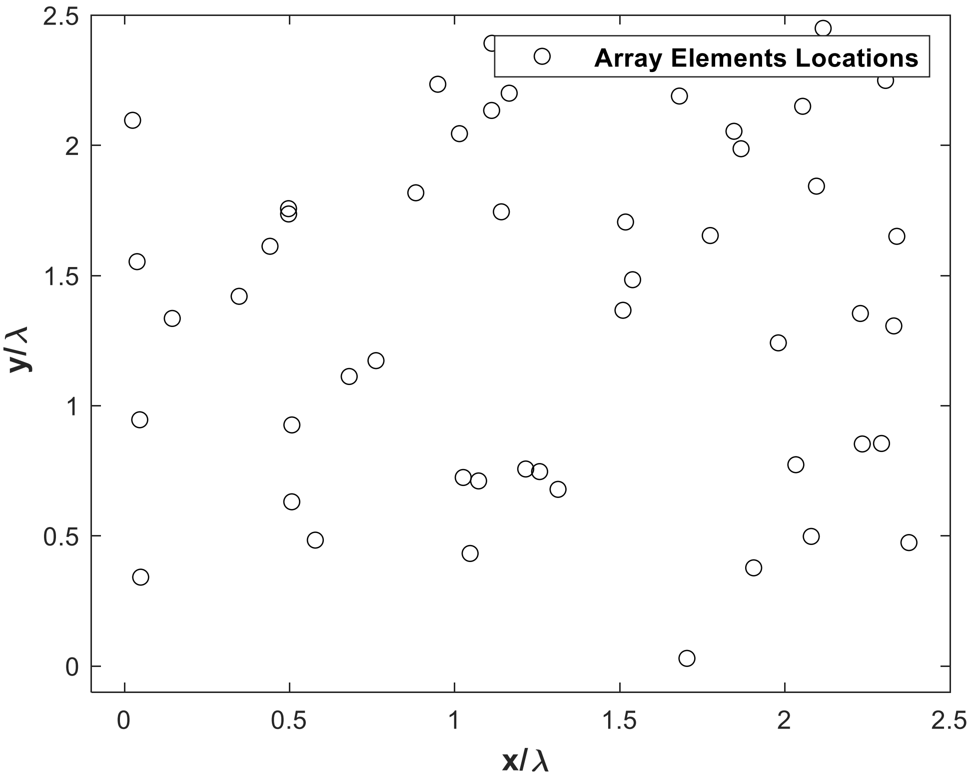


Figure (4.32):Array Element Location of Optimized Random Planar Array 49 Element.

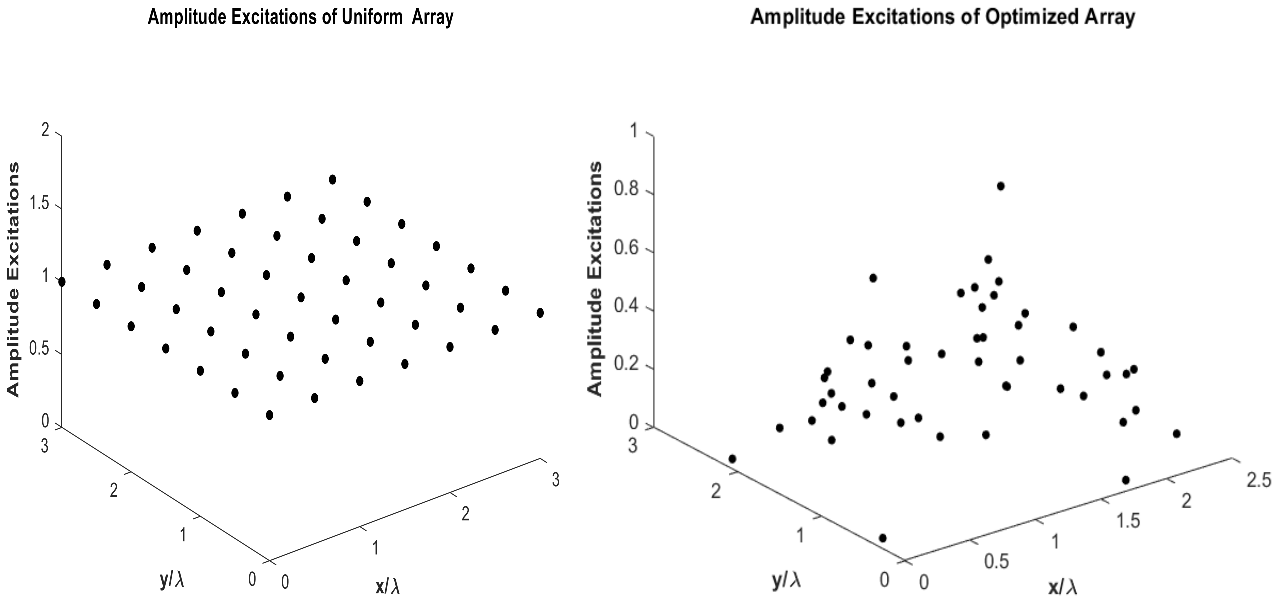


Figure (4.33):Amplitude Excitation of Uniform and Optimized Random Planar Array with 49 Elements for $\Omega_{BW}=3.7^0$.

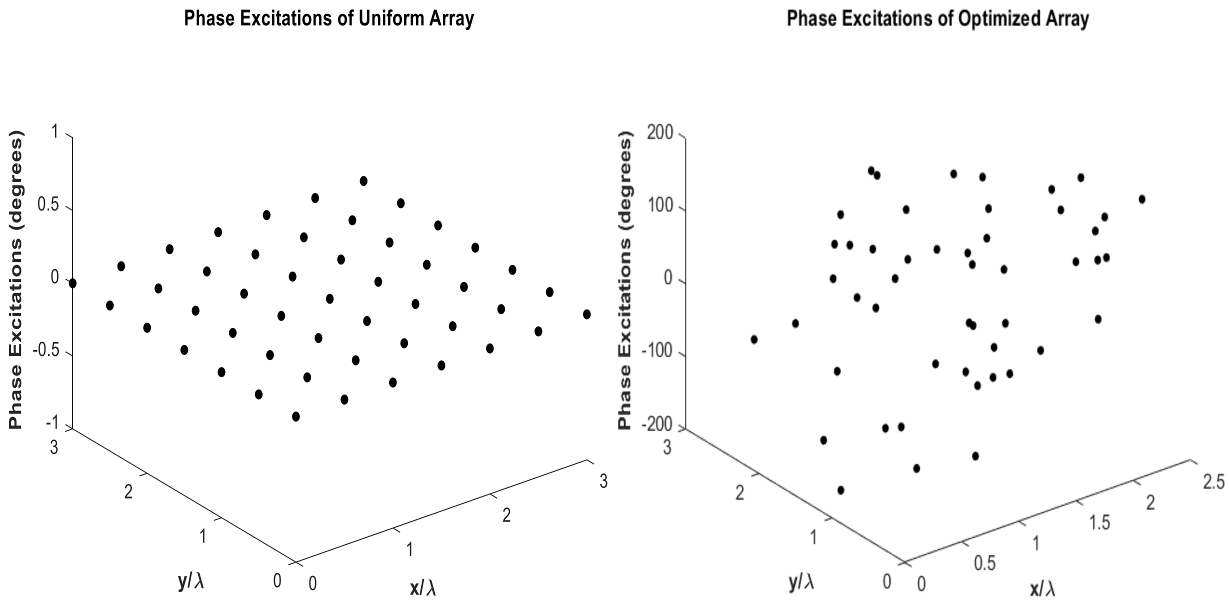


Figure (4.34): Phase Excitation of Uniform and Optimized Random Planar Array with 49 Elements for $\Omega_{BW}=3.7^0$.

- For Random planar array the second case changing the array elements to N=64 and $\Omega_{BW}=2.84^0$ the results for this case shown in figures from (4.35) to (4.38)

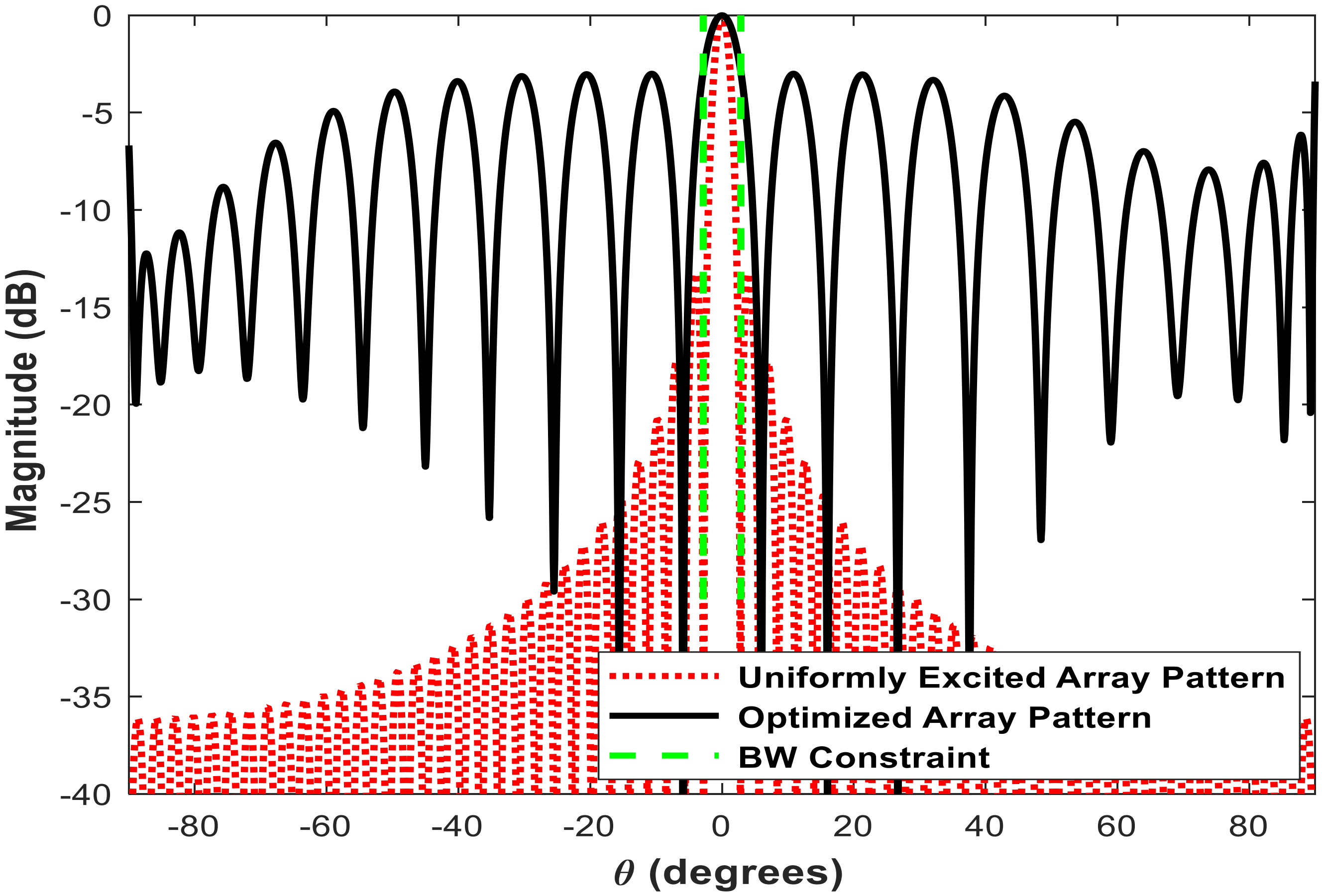


Figure (4.35):The Optimized Radiation Pattern of the Random Planar Array with 64 Element for $\Omega_{BW}=2.84^0$.

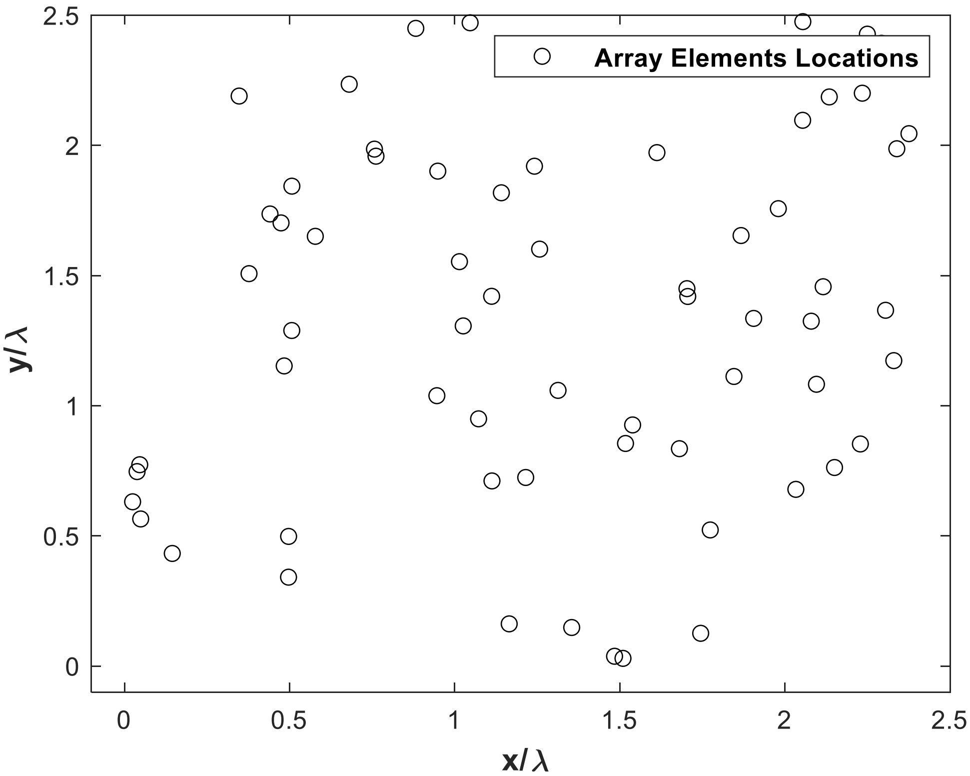


Figure (4.36): Array Element Location of Optimized Random Planar Array 64 Element.

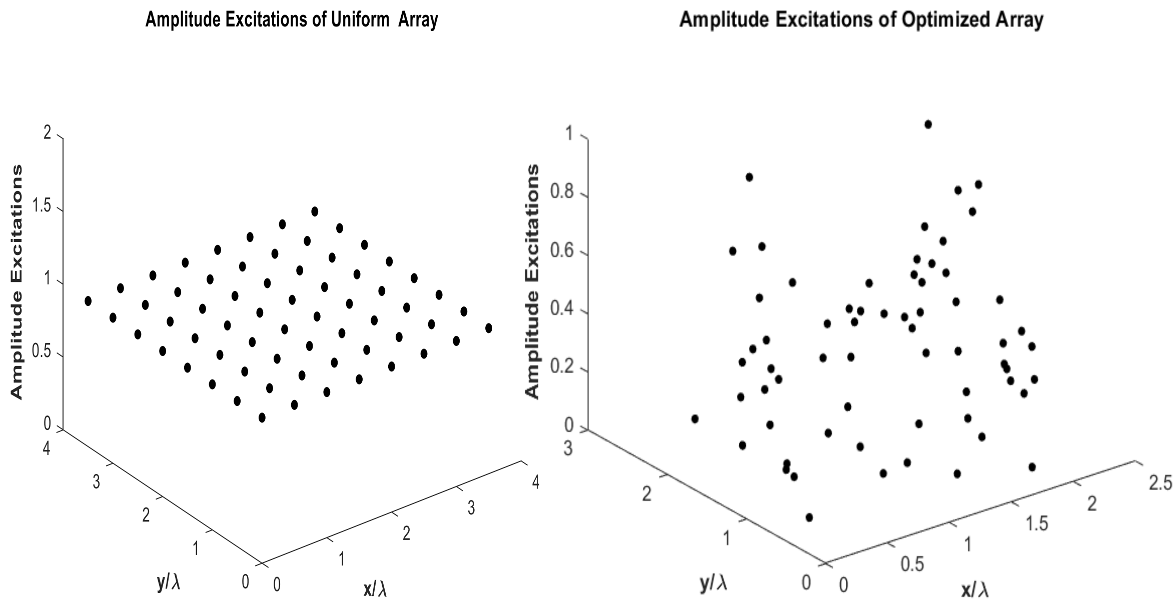


Figure (4.37): Amplitude Excitation of Uniform and Optimized Random Planar Array with 64 Elements for $\Omega_{BW}=2.84^0$.

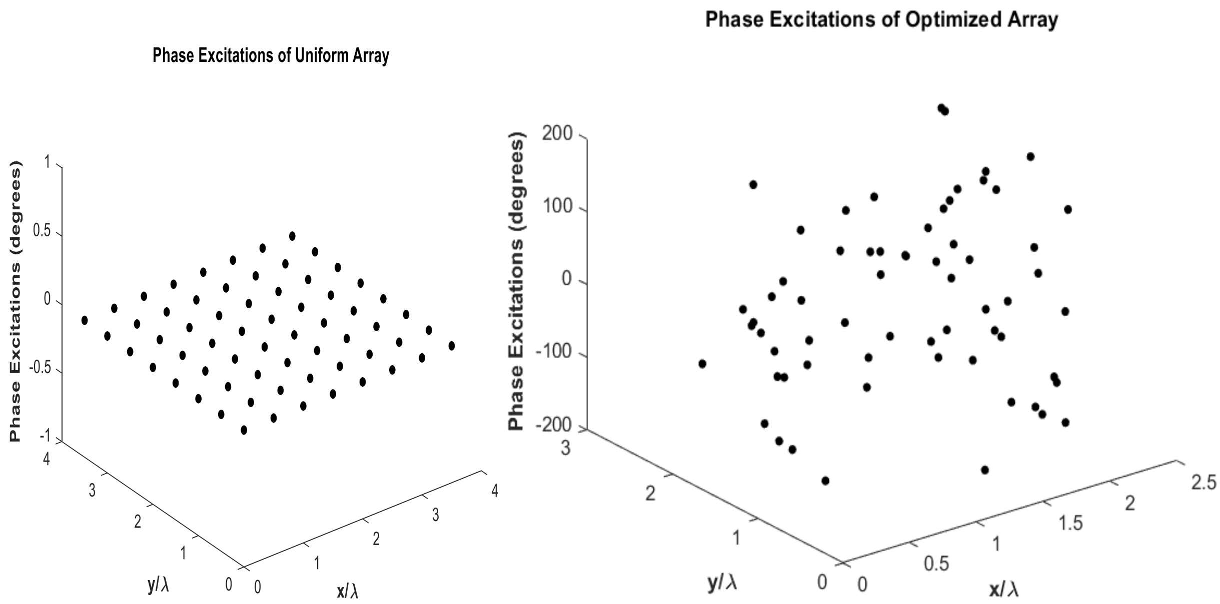


Figure (4.38): Phase Excitation of Uniform and Optimized Random Planar Array with 64 Elements for $\Omega_{BW}=2.84^0$.

Table (4.4) Compromised for varied number of element for three types of optimized array Linear ,planar and random planar

	N×M	Ω_{BW} (deg)	SLL(dB)	Directivity(dB)
Optimized uniform linear array	36	5^0	-35.74	34.363
	49	3.7^0	-37.46	36.907
	64	2.84^0	-37.53	39.248
Optimized uniform planar array	36	5^0	-8.59	23.526
	49	3.7^0	-7.44	22.879
	64	2.84^0	-5.81	22.074
Optimized random planar array	36	5^0	-7.68	22.406
	49	3.7^0	-5.25	19.563
	64	2.84^0	-3	17.458

From the figures for varying the number of elements for three types the linear ,planar and random planar antenna array and table (4.4) only for linear array when increasing the number of element the SLL lowering and the directivity increase but in uniform and random planar array the reverse occurred.

4.4 Feasible Minimum Beam Width for a Given SLL

In this example, a feasible minimum beam width for a given SLL is investigated where the SLL was fixed at -30 dB and a feasible minimum beam width for linear, planar, and random arrays was computed . In all cases the number of element fixed to (36 element) and target angle to 0^0 .The results for uniform linear array ,uniform planar array and random planar array with a feasible minimum beam width for a given SLL are shown in figures(4.39) to(4.48) . From these figures, it can be seen that the feasible minimum beam width for linear, planar, and random arrays was $\Omega_{BW} = 5^0$, $\Omega_{BW} = 11^0$, and $\Omega_{BW} = 13^0$ respectively for getting SLL=-30 dB.

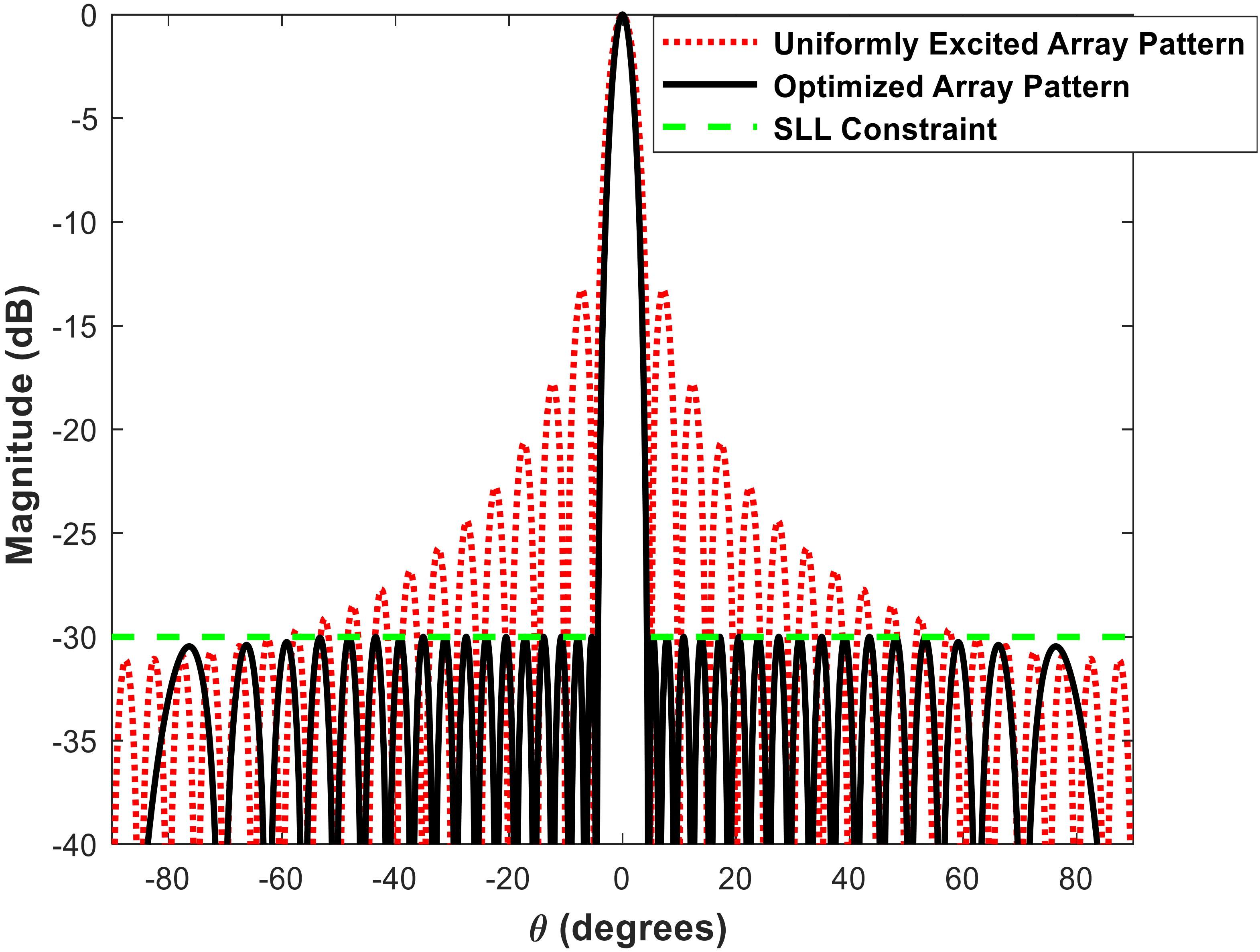


Figure (4.39): Array Pattern of Linear Optimized Array for SLL=-30dB and N=36 Element.

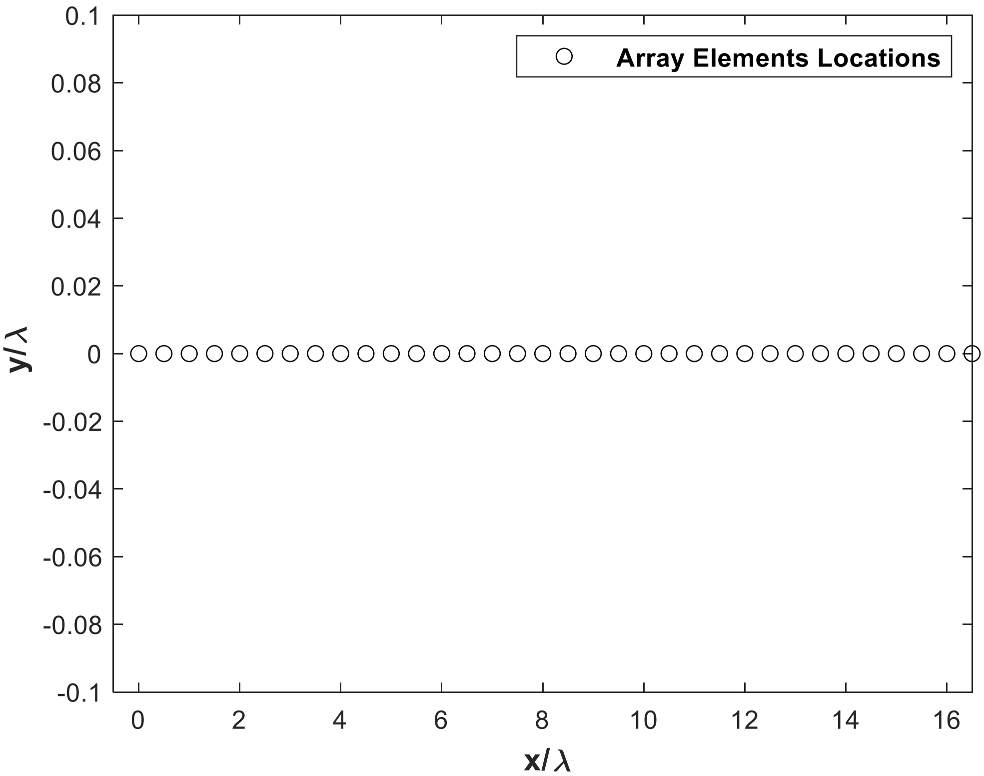


Figure (4.40): Linear Array Elements Locations.

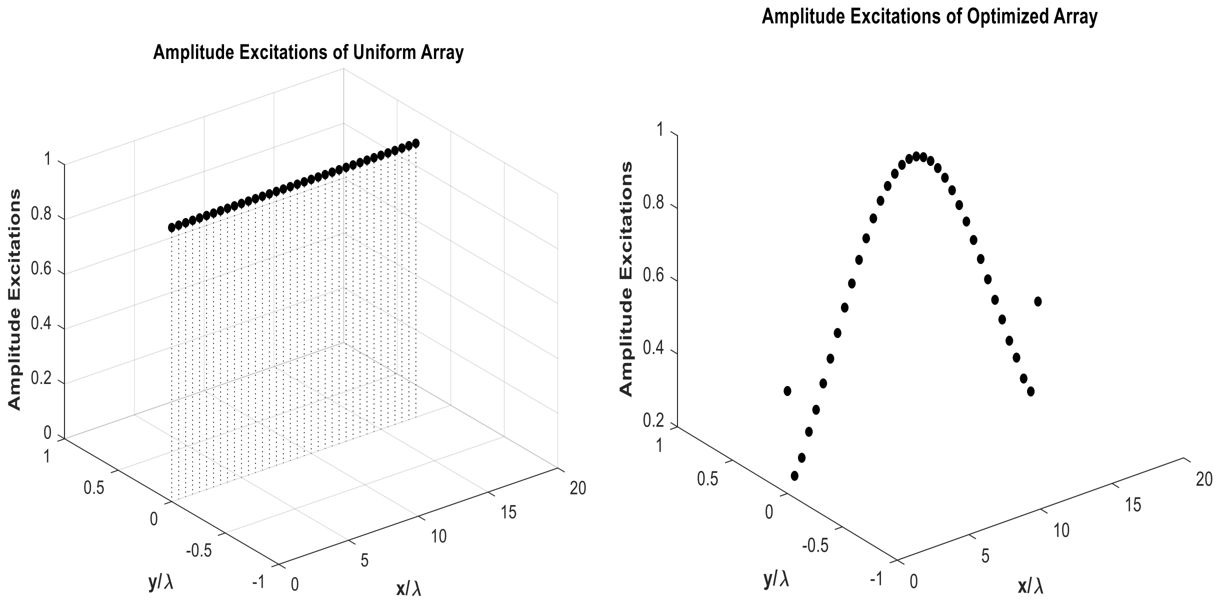


Figure (4.41): Amplitude Excitation of Uniform and Optimized Linear Array.

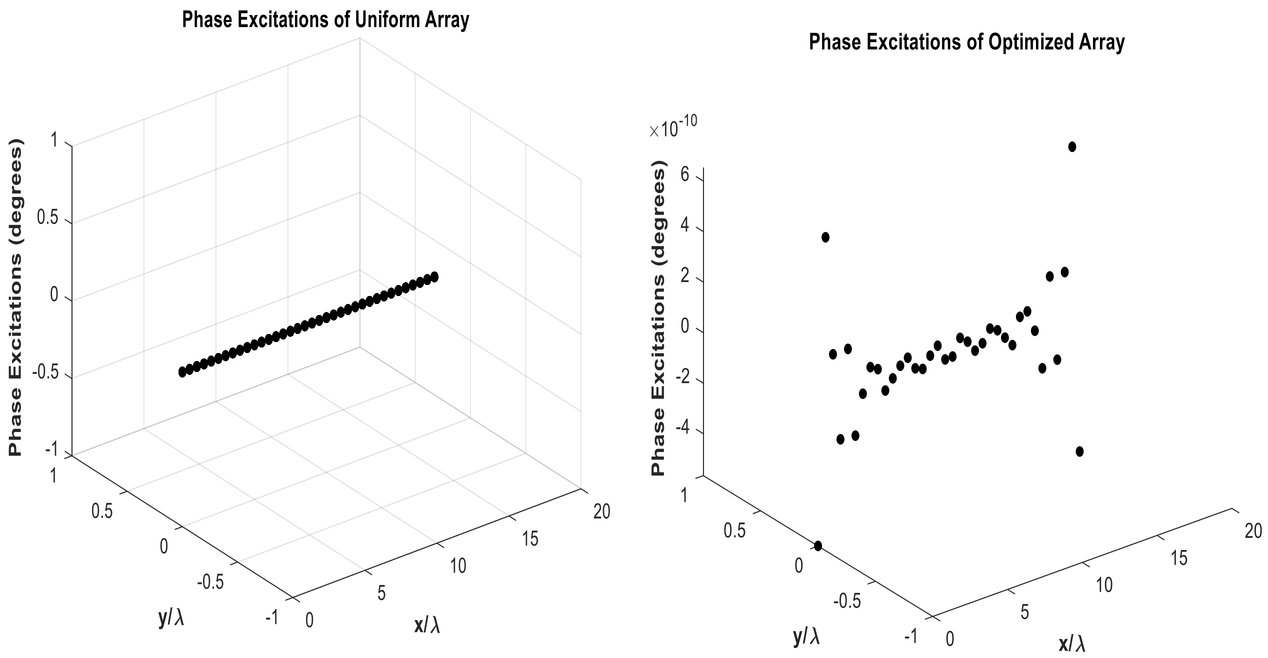


Figure (4.42): Phase Excitation of Uniform and Optimized Linear Array.

- Planar uniform Array with SLL=-30dB and N×M=36

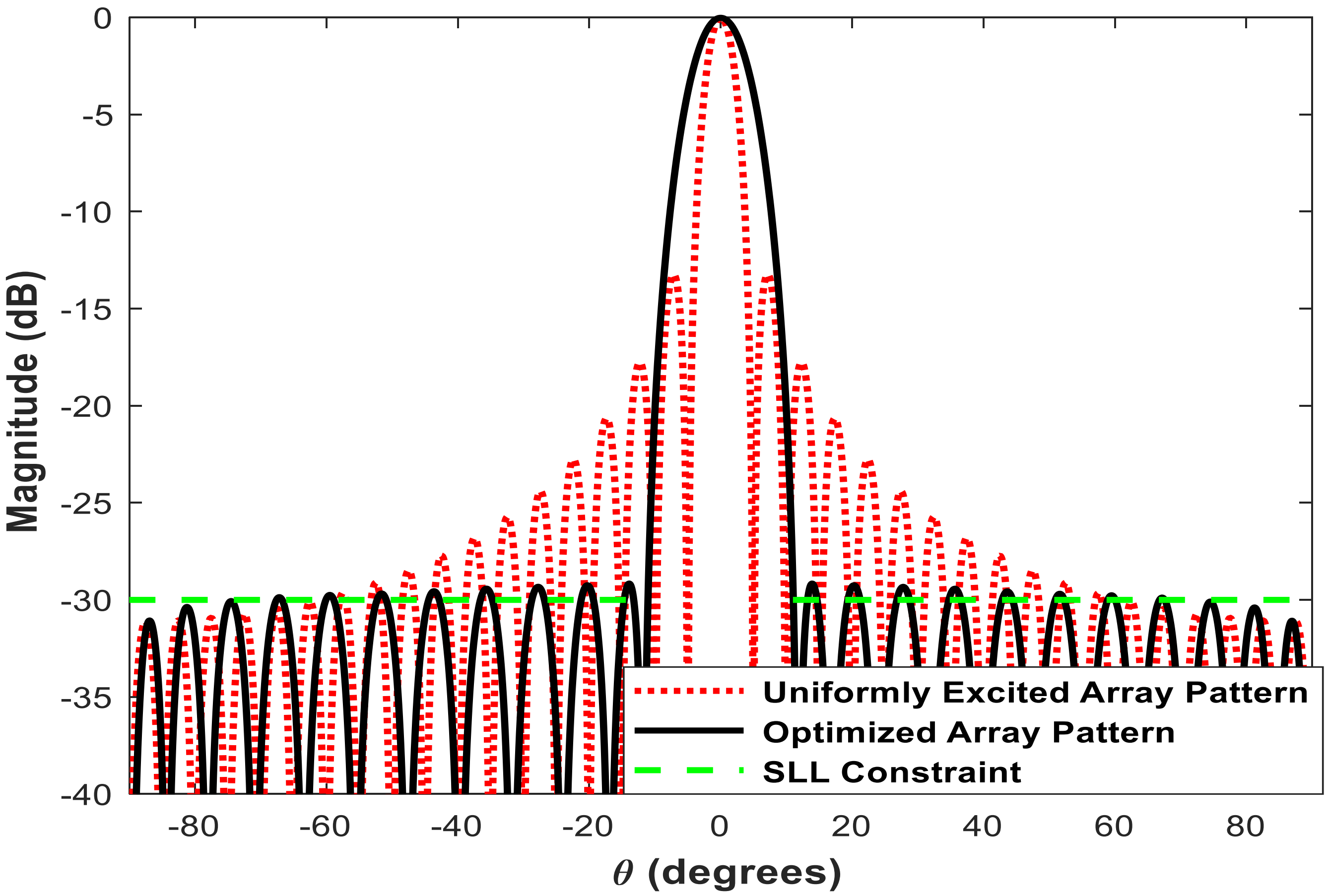


Figure (4.43): Array Pattern of Uniform Planar Optimized Array for SLL=-30dB and N×M=36 Element.

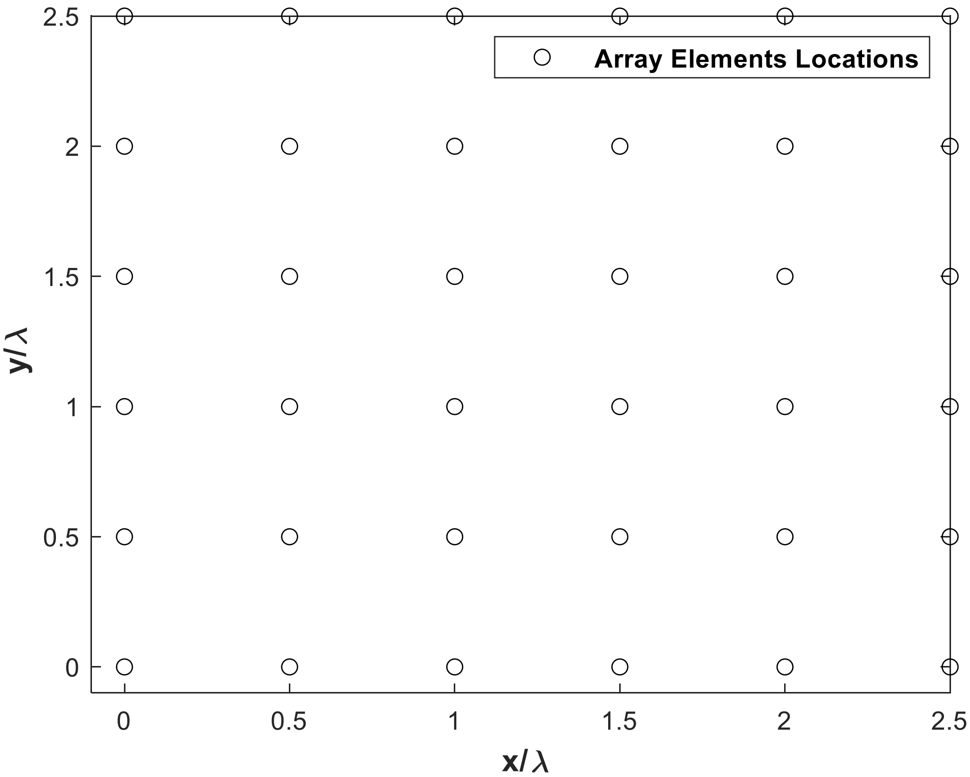


Figure (4.44): Planar Array Elements Location.

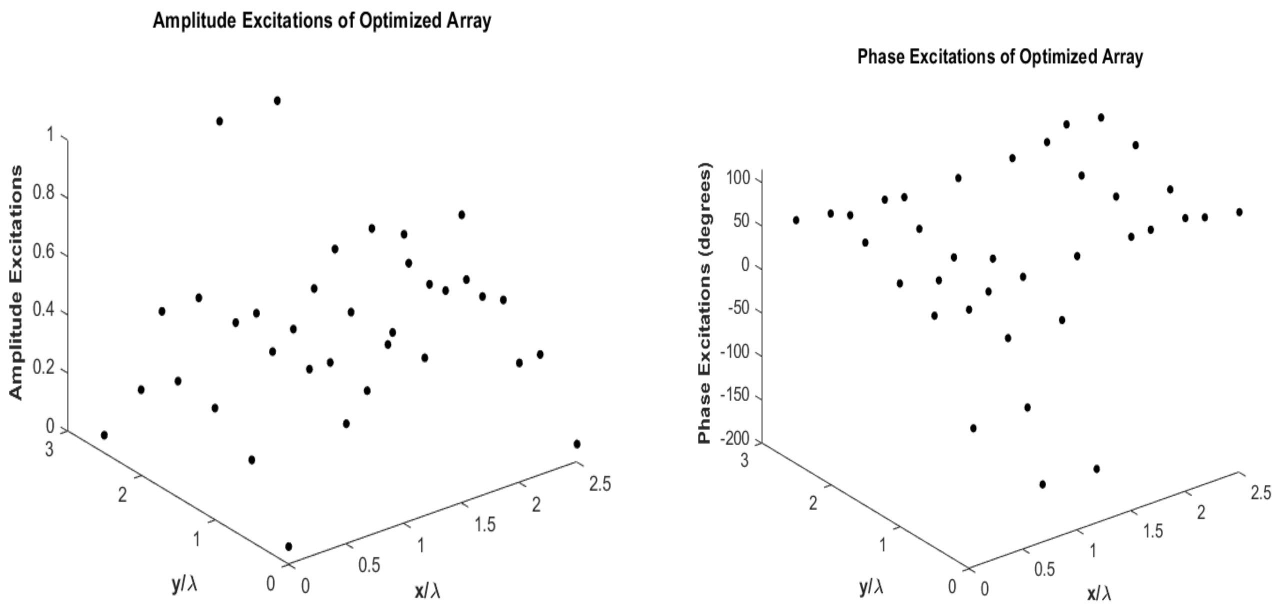


Figure (4.45): Amplitude and Phase Excitation of Optimized Planar Array with SLL=-30dB and N×M=36.

Random planar array with SLL=-30dB and N=36

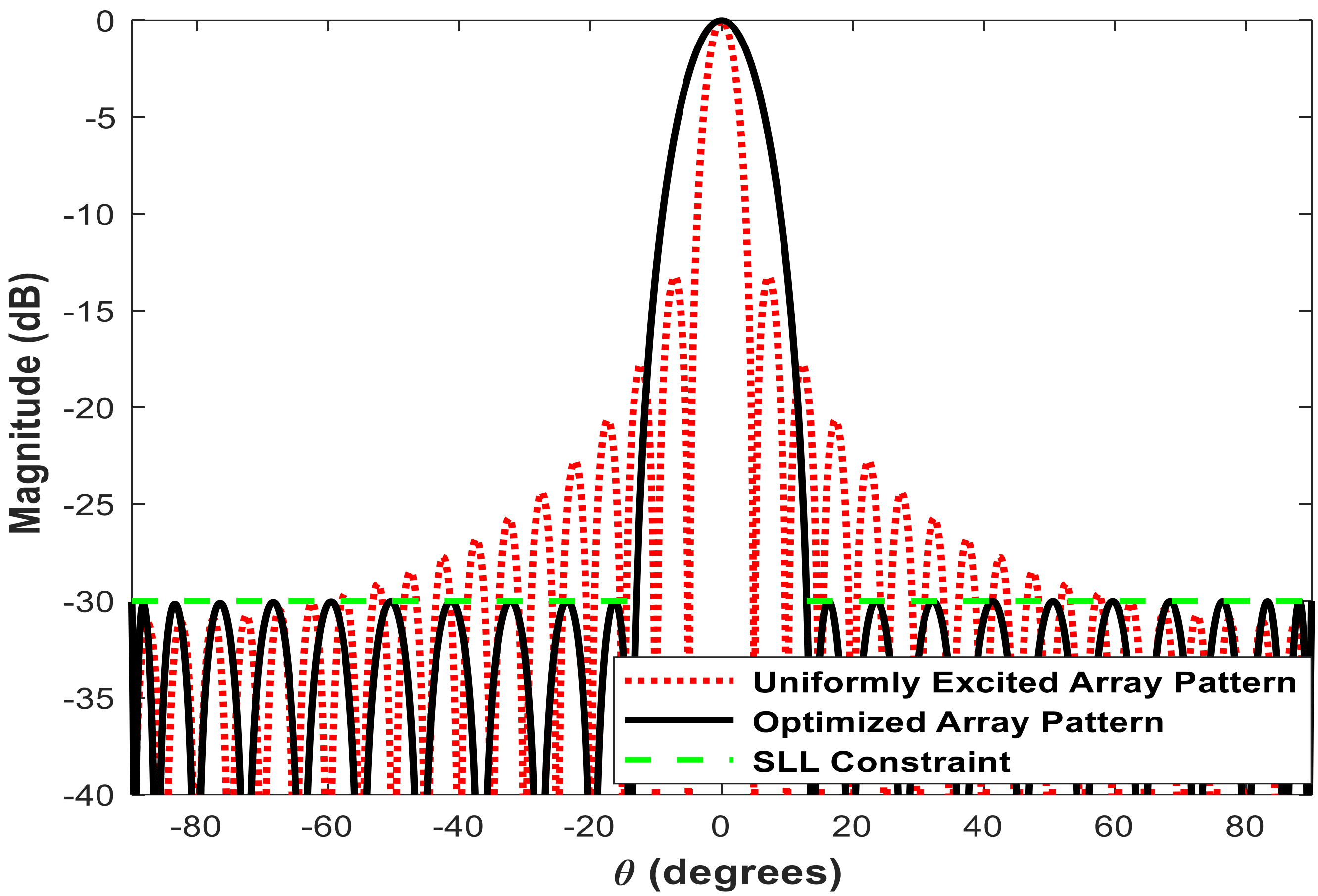


Figure (4.46): Array Pattern of Random Planar Optimized Array for SLL=-30dB and N×M=36 Element.

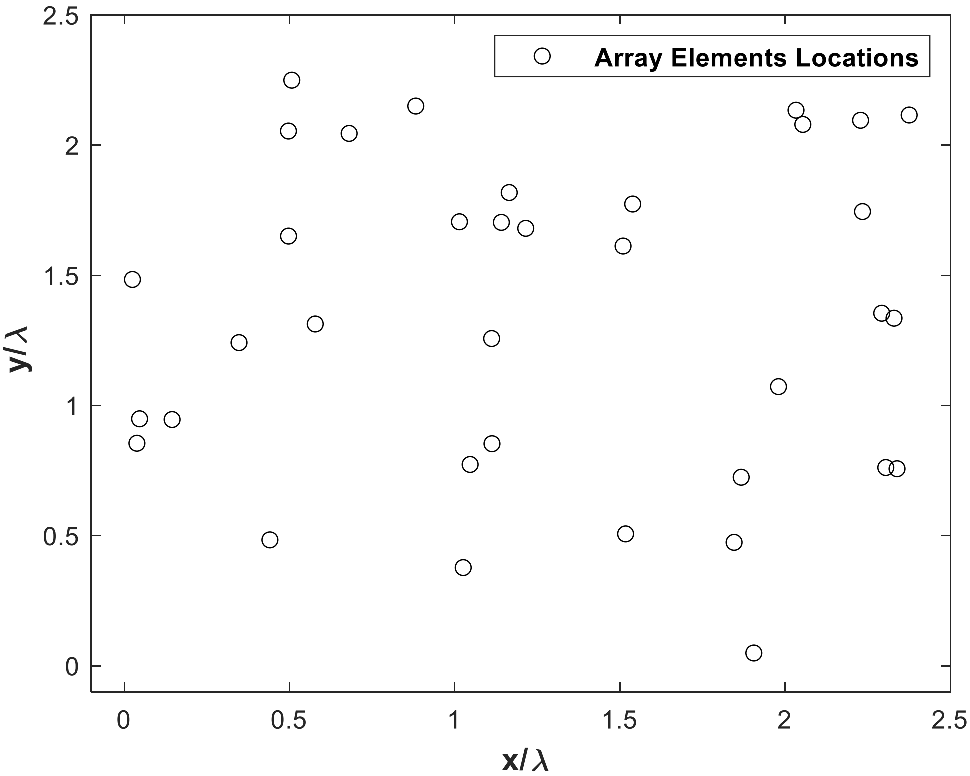


Figure (4.47): Array Element Location of Optimized Random Planar Array 36 Element.

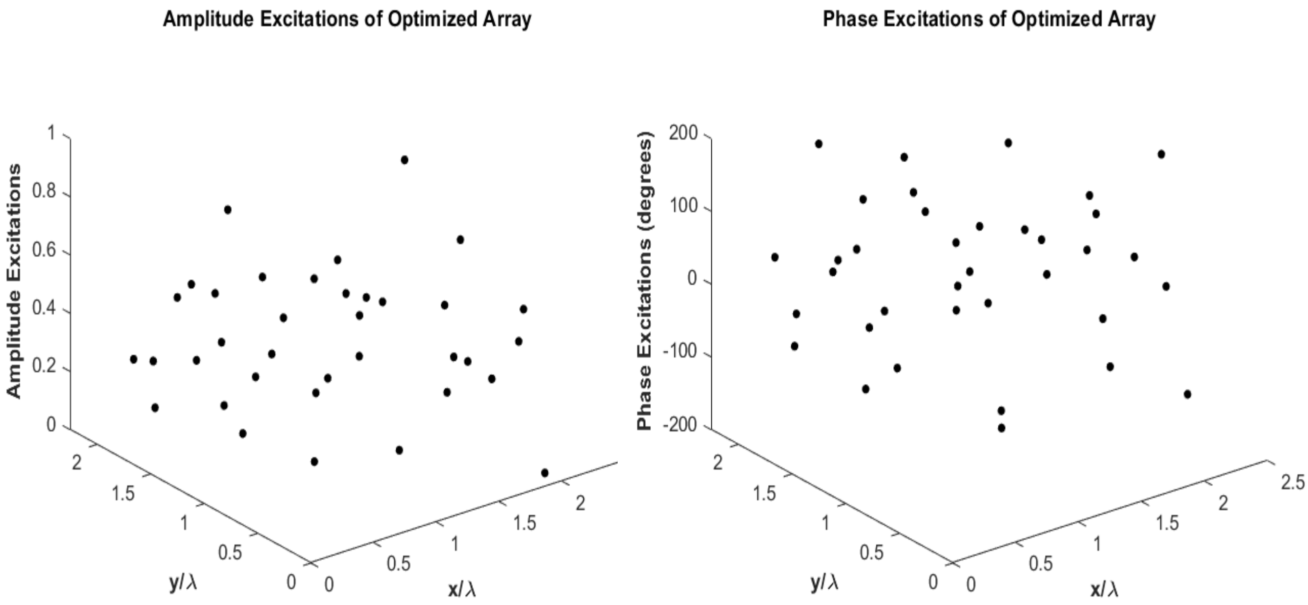


Figure (4.48):Amplitude and Phase Excitation of Optimized Random Planar Array.

Finally, the two figures (4.49) and (4.50) and tables (4.5),(4.6)(4.7) show the variations of the minimum feasible beam width and the directivities for different values of the SLL start from -10 to -45 for three types of array (linear ,planar and random planar array). It can be seen that the higher SLL results in narrower beam width. These results fully confirm the effectiveness of the convex optimization algorithm for linear, planar, and random array configurations.

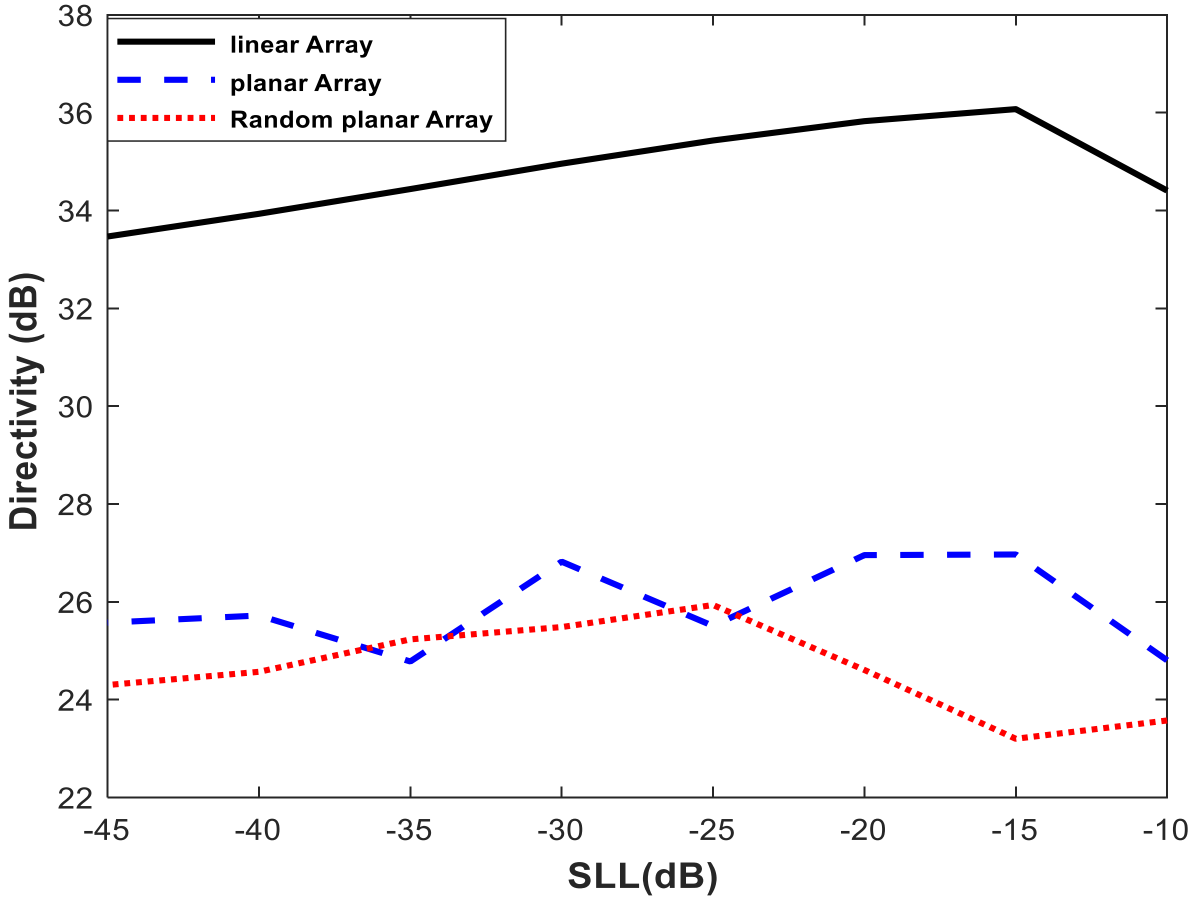


Figure (4.49): Variation of Directivity (dB) and Versus Given SLL (dB)

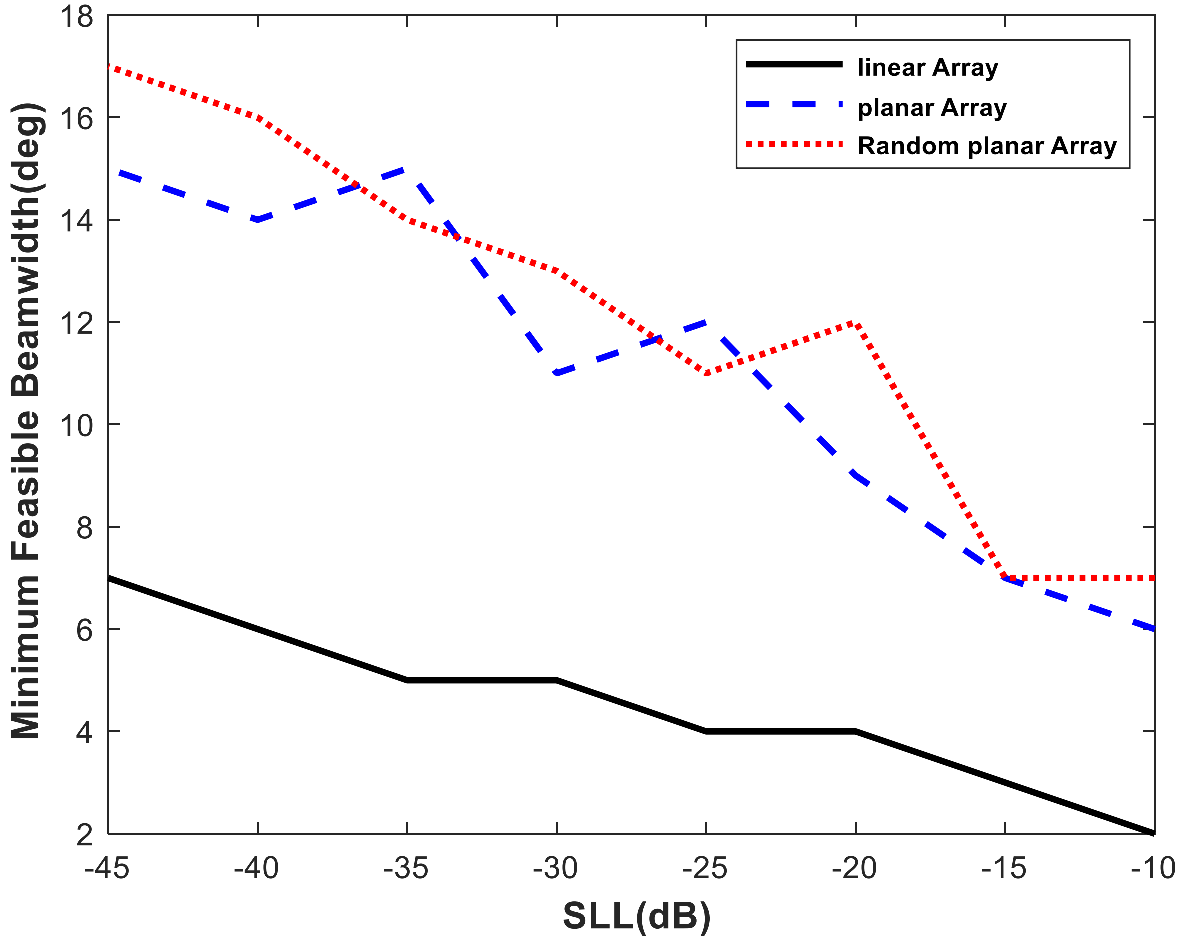


Figure (4.50):Variation of Minimum Feasible Beamwidth(deg)and
Versus Given SLL(dB)

Table (4.5): Uniform Linear Array with Varied Side Lobe Level SLL and N=36.

SLL(dB)	Directivity (dB)	Beamwidth(deg)
-10	34.407	2
-15	36.073	3
-20	35.827	4
-25	35.432	4
-30	34.9586	5
-35	34.439	5
-40	33.933	6
-45	33.469	7

Table (4.6): Uniform Planar Array with N*M=36 and Varied Side Lobe Level (SLL).

SLL(dB)	Directivity (dB)	Beamwidth(deg)
-10	24.804	6
-15	26.968	7
-20	26.955	9
-25	25.507	12
-30	26.821	11
-35	24.780	15
-40	25.720	14
-45	25.575	15

Table (4.7): Random Planar Array with Varied Side Lobe Level (SLL) and N=36.

SLL(dB)	Directivity (dB)	Beamwidth(deg)
-10	23.574	7
-15	23.20	7
-20	24.607	12
-25	25.935	11
-30	25.484	13
-35	25.232	14
-40	24.569	16
-45	24.299	17

CHAPTER FIVE

CONCLUSIONS AND FUTURE WORK

5.1 CONCLUSIONS

In this thesis, the three antenna array configurations uniform linear array, uniform planar array, and random planar array have all been successfully optimized using convex optimization to achieve the desired radiation patterns of each type to obtain the desired characteristics, which in most applications is to have the lowest side-lobe level with increased directivity and without changing half power beam width . The excitation amplitudes and phases of the array components are subjected in the optimization approach to either minimize sidelobe levels for a given beam width or minimize the beam width for a given sidelobe level. It has been demonstrated from the outcomes of the linear, planar, and random array topologies that a much lower SLL may be achieved for greater beam width values at the expense of poorer directivities. Moreover, the performance of the linear arrays was found to outperform in terms of minimum feasible SLL for a given narrow beamwidth compared to other two configurations. When the number of elements was raised in proportion to the first case's maximum directivity and minimize side lobe level, the uniform linear array outperformed the uniform planar array and random planar array in terms of performance.

This is mainly due to the fact that the linear array has wider space diversity. On the other hand, the three array configurations perform well and provide feasible minimum beam width for relatively high SLL. These results fully confirm the capability of the proposed two optimization methods.

5.2. FUTURE WORK

Future research can expand on and go deeper into the methodologies outlined in this thesis. The following are some ideas:

1. In this thesis, the element excitation amplitudes and phases are only optimized to obtain the minimum side lobe level with fixed half power beam width and obtain minimum half power beam width with fixed side lobe. The distance between the elements, their number, and other parameters can be employed in optimization to get the same or different characteristics.
2. The array configuration not only uniform linear ,planar array ,and random planar array there are another configuration like circular array and conformal array which can also be optimized with convex optimization.

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الخلاصة

اعتمادًا على كيفية استخدام هوائي المصفوفة في الانظمة العملية، يمكن ترتيب العناصر المشعة لمصفوفة الهوائي بأي شكل هندسي مثل الخطي او المستوي . تعد المصفوفة الخطية ذات البعد الواحد او المستوية ذات البعدين أكثر التصميمات المستخدمة في التطبيقات العملية. تعتبر هوائيات المصفوفة الخطية أو المستوية منتظمة عندما تكون المسافات بين عناصر المصفوفة منتظمة ، ومصفوفات عشوائية عندما تكون المسافات عشوائية. للحصول على افضل اداء للنظام وتحديد اتساع الإثارة ومراحل مكونات الصفيف في مثل هذه التطبيقات ، من الضروري اتباع نهج تحسين بسيط. في هذه الأطروحة ، يتم تحقيق توليف مخططات صفيف الهوائي الخطي والمستوي والعشوائي في ظل ظروف تقييد محددة باستخدام خوارزمية التحسين المحدب بدلاً من الخوارزميات المثلى ذات الطبيعة العشوائية المتكررة التي تتميز بكونها صعبة وتحتاج الى وقت اطول. يمكن أن تكون هذه المحددات إما عرض الحزمة ثابت للفص الرئيسي لنمط اشعاع هوائي المصفوفة عند تقليل مستوى الفصوص الجانبية لنمط الاشعاع. أو بالامكان جعل مستوى الفصوص الجانبية ثابتا عند قيمة معينة عند تقليل عرض الحزمة للفص الرئيسي .

أولاً ، تم التحقيق في مشكلة الحصول على الحد ألادنى الممكنة من مستوى الفصوص الجانبية لعرض حزمة معينة. بعد ذلك ، تم اعادة المشكلة لغرض الحصول على ادنى عرض حزمة ممكنة للفص الرئيسي عند مستوى معين للفصوص الجانبية. تم تطبيق كلتا طريقتي التحسين على تكوينات هوائي المصفوفة الخطية والمستوية والعشوائية. أظهرت نتائج المحاكاة بالحاسبة من فعالية طرق التحسين المقترحة حيث تم تخفيض الفصوص الجانبية لمستويات منخفضة جدا مع الحفاظ على عرض حزمة مساوي لهوائيات المصفوفة المنتظمة. أفضل النتائج كانت لمصفوفة الهوائيات الخطية, بينما لوحظ زيادة في الفصوص الجانبية لمصفوفات الهوائيات المستوية والعشوائية بسبب تحديد توزيع عناصرها ضمن مساحة محددة

إقرار المشرف

نشهد بأن هذه الرسالة الموسومة (**تحسين عرض الحزمة وتقليل مستوى الفصوص الجانبية باستخدام خوارزمية التحسين المحدب في هوائيات المصفوفات الخطية والمستوية والعشوائية**) تم اعدادها من قبل الطالبة (**رنا رعد شاكر**) تحت اشرافنا في قسم هندسة الاتصالات / كلية هندسة الالكترونيات / جامعة نينوى، وهي جزء من متطلبات نيل شهادة الماجستير/علوم في اختصاص هندسة الاتصالات .

التوقيع:

الاسم: أ.د.جعفر رمضان محمد

التاريخ: / /2022

إقرار المقوم اللغوي

اشهد بأنه قد تمت مراجعة هذه الرسالة من الناحية اللغوية وتصحيح ما ورد فيها من أخطاء لغوية وتعبيرية وبذلك أصبحت الرسالة مؤهلة للمناقشة بقدر تعلق الأمر بسلامة الأسلوب أو صحة التعبير.

التوقيع:

الاسم: أ.م.د.اسماعيل فتحي حسن

التاريخ: / /2022

إقرار رئيس لجنة الدراسات العليا

بناءً على التوصيات المقدمة من قبل المشرف والمقوم اللغوي أرشح هذه الرسالة للمناقشة.

التوقيع:

الاسم: أ.م.د محمود احمد محمود

التاريخ: / /2022

إقرار رئيس القسم

بناءً على التوصيات المقدمة من قبل المشرف والمقوم اللغوي ورئيس لجنة الدراسات العليا أرشح هذه الرسالة للمناقشة.

التوقيع:

الاسم: أ.م.د محمود احمد محمود

التاريخ: / /2022

إقرار لجنة المناقشة

نشهد بأننا أعضاء لجنة التقويم والمناقشة قد اطلعنا على هذه الرسالة الموسومة **(تحسين عرض الحزمة وتقليل مستوى الفصوص الجانبية باستخدام خوارزمية التحسين المحدب في هوائيات المصفوفات الخطية والمستوية والعشوائية)** وناقشنا الطالبة **(رنا رعد شاكر)** في محتوياتها وفيما له علاقة بها بتاريخ 30/ 11 /2022 وقد وجدناها جديرة بنيل شهادة الماجستير/علوم في اختصاص هندسة الاتصالات .

التوقيع:
رئيس اللجنة: أ.م.د.يونس محمود عبوش
التاريخ: / /2022

التوقيع:
عضو اللجنة: أ.د. ياسر احمد فاضل
التاريخ: / /2022

التوقيع:
عضو اللجنة: م.د.ادهم معن صالح
التاريخ: / /2022

التوقيع:
عضو اللجنة (المشرف): أ.د جعفر رمضان محمد
التاريخ: / /2022

قرار مجلس الكلية

اجتمع مجلس كلية هندسة الالكترونيات بجلسته .... المنعقدة بتاريخ: / / 202
وقرر المجلس منح الطالبة شهادة الماجستير علوم في اختصاص هندسة الالكترونيك

مقرر المجلس: أ.م.د. صدقي بكر ذنون
التاريخ: / / 2022

رئيس مجلس الكلية: أ.د. خالد خليل محمد
التاريخ: / /2022

تحسين عرض الحزمة وتقليل مستوى الفصوص الجانبية باستخدام خوارزمية التحسين المحدب في هوائيات المصفوفات الخطية والمستوية والعشوائية

رسالة تقدمت بها

رنا رعد شاكر العبيدي

إلى

مجلس كلية هندسة الالكترونيات

جامعة نينوى

كجزء من متطلبات نيل شهادة الماجستير

في

هندسة الاتصالات

بإشراف

أ.د .جعفر رمضان محمد

1444 هـ

2022م

جامعة نينوى

كلية هندسة الالكترونيات

قسم هندسة الاتصالات

تحسين عرض الحزمة وتقليل مستوى الفصوص الجانبية باستخدام خوارزمية التحسين المحدب في هوائيات المصفوفات الخطية والمستوية والعشوائية

رنا رعد شاكر العبيدي

رسالة ماجستير علوم في هندسة الاتصالات

باشراف

أ.د .جعفر رمضان محمد

1444 هـ

2022م