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Study and Design of the Adaptive Array for Interference Cancellation in the 5G Applications

By

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M.Sc. Dissertation In
Communication Engineering

Supervised by
Prof. Dr. Jafar Ramadhan Mohammed

2022 A.D. **1444 A.H.**

Study and Design of the Adaptive Array for Interference Cancellation in the 5G Applications

Dissertation Submitted By

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To

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As a Partial Fulfillment of the Requirements For the Degree of Master of Science

In Communication Engineering

Supervised by

Prof. Dr. Jafar Ramadhan Mohammed

2022 A.D. **1444 A.H.**

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

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ABSTRACT

One of the most promising solutions for interference suppression in the congested spectrum environment of wireless communication systems such as 5G and beyond is using adaptive antenna arrays. However, some practical issues might arise when it comes to actual implementation, such as a high complexity weighting network caused by the deployment of many of the adaptive controllers, leading to a slow convergence speed. Therefore, in this dissertation , three new adaptive array configurations are proposed. The first configurations is a regular adaptive subarrays. .Whereas in this configuration all array elements are divided evenly into multiple subarrays, and each subarray has an equal number of array elements. Subsequently, the second configuration is called partially adaptive elements where only certain array elements are made adaptive, while the rest are constant. The last configuration is called partially adaptive irregular subarrays, since the adaptive elements are divided into smaller partially adaptive subarrays. The proposed configurations provide many benefits over the conventional fully adaptive array, including a reduction in the number of controllable elements; thus, the optimizer's convergence speed was dramatically accelerated without the need for sophisticated array configurations which in turn reduce the manufacturing costs. On the other hand, Simulation findings demonstrated the effectiveness of the proposed array weighting configurations in terms of quicker convergence speed, improved interference suppression and reduction in interference signals to more than -20 dB, which is adequate for 5G and future wireless communication systems. Finally, an adaptive antenna array was simulated using CST 2019 software and fabricated in order to validate the effectiveness of the proposed work.

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LIST OF ABBREVIATIONS

Abbreviation	Name
5G	Fifth Generation
AF	Array Factor
AOA	Angle of Arrival
CG	Conjugate Gradient
CGM	Conjugate Gradient Method
CMA	Constant Modulus Algorithm
CNC	Computer Numerical Control
DOA	Direction of Arrival
FLMS	Fractional Least Mean Square
INRs	Interference to Noise Ratios
ISI	Inter-Symbol Interference
LMS	Least Mean Square
LS	Least Square
LTE	Long Term Evolution
MaxSIR	Maximum Signal-to-Interference Ratio
MIMO	Multiple Input Multiple Output
MMSE	Minimum Mean Square Error
MSE	Mean Square Error
NAF	Normalized Array Factor
NLMS	Normalized Least Mean Square
PCB	Printed Circuit Board

PSO	Particle Swarm Optimization
RLS	Recursive Least Squares
SA	Smart Antenna
SA	Spectrum Analyzer
SARLS	Subarray Asynchronous Recursive Least Square
SG	Signal Generator
SGD	Stochastic Gradient Descent
SINR	Signal to Interference Plus Noise Ratio
SIR	Signal to Interference Ratio
SLL	Side Lobe Level
SLMS	Sign Least Mean Square
SMI	Sample Matrix Inversion
SNR	Signal to Noise Ratio
SOI	Signal of Interest
ULA	Uniform Linear Array
VNA	Vector Network Analyzer
VSS-LMS	Variable Step Size - Least Mean Square
VSSNLMS	Variable Step Size Normalized Least Mean Square

LIST OF SYMBOLS

Symbol	Name
$\bar{R}_{ii}$	Correlation matrix for interferers
$\bar{R}_{nn}$	Correlation matrix for noise
$\bar{R}_{ss}$	Signal correlation matrix
$\bar{R}_{uu}$	Array correlation matrices for the undesired signal
$\bar{a}_i$	M-element array steering vector
$\bar{x}_i$(k)	Interfering signals vector
${\sigma^2}_s$	The weighted array output power for the desired signal
${\sigma^2}_u$	The weighted array output power for the undesired signals
$\bar{n}$(k)	Zero mean gaussian noise for each channel
$\bar{u}$(k)	Undesired signal
∅	Phase difference between incoming waves at consecutive elements
μ	Step size
A	The signal amplitude
a(θ)	Steering vector
AF	The array factor
d	Distance between successive antenna phase centers in the array
D	The maximum dimension of the antenna aperture
d(k)	The reference signal
e(k)	The error between a desired signal and the array output

f_c	The carrier frequency
M	Number of element in each subarray
N	Number of antenna elements
P	Number of the adaptive elements in partially adaptive element
Q	Number of subarray in fully adaptive subarray
R	The distance between transmitting and receiving
s(k)	Desired signal
s(t)	The incident waves in the narrow band
W	Weight
W_{sub}	Subarray weights
x(k)	The electrical input signals
y(k)	The antenna array's output signal
λ	The wavelength in free space
λ_{max}	The biggest eigenvalue
θ	Angle of arrival w.r.t normal

CHAPTER ONE

INTRODUCTION

1.1 Background

In recent years, the demand for better wireless communication performance in coverage, user capacity, and providing high transmission quality has constantly increased. To mitigate interference and improve user capacity, new promising technology is developed called smart antenna [1].

Smart antennas can steer the main beam toward the intended direction while placing null at undesired direction and eliminating interference. A smart antenna is made up of an antenna array and a Digital Signal Processor (DSP) [2]. The ability to produce adaptive beams is critical in smart antenna systems. An adaptive antenna array has been widely employed in a variety of applications, such as acoustic signal processing, scan and track radar, and cellular systems such as LTE and 5G [3].

The primary role of antennas is to transmit and receive radio signals properly [4],[5]; however, smart antennas also perform the following functions:

1. Estimation of the Direction Of Arrival (DOA): Antennas are necessary to determine the direction of arrival of the required incoming signal to offer efficient transmission and reception.
2. Beamforming: Based on the analyses of the DOA, the circuitry inside the antenna can optimize the beam pattern in a specific direction to offer the required performance. Beamforming is a

technique that uses an array of antennas to guide a wireless signal in a specified direction rather than spreading the signal in all directions.

The directional gain of the antenna is adjusted by changing the phase or the amplitude individually, or both of them at each single element .The weighted signals are combined together and passed to the controller. These weights are calculated adaptively in order to respond to changes in the signal environment. Several adaptive beamforming techniques are utilized to decrease the error between the necessary signal and the array output by adjusting the weights to meet optimization criteria [3, 6].

Continuous adaptation to any changes in the electromagnetic environment should be possible by continually updating and recalculating the optimal array weights. For instance, directing the array pattern's main beam in the direction of the desired signal and its nulls in the direction of the interfering signals [7]. Modern wireless communication is quickly growing as a result of globalization. Because of continual changes in the channel environment, the required signal arrival angle in wireless mobile communication systems changes over time. As a result, ongoing modification of the array's weights is necessary to obtain the desired signal, which is accomplished by optimization approaches such as Least Mean Squares (LMS) algorithm. For each repetition, the reference signal is utilized to update the weights [8].

1.2 Literature Survey

In 2000, authors presented two methods for adaptable arrays. The first method, which is used for arrays with many elements, is based on adjusting the amplitudes of both ends of array elements in order to direct a null toward the direction of the array's two first side lobes on each side of the main lobe. The second method was applied to arrays with few number of elements. And it is based on using an auxiliary parallel array made up of 2N elements, as well as controlling the weight coefficients (with equal amplitudes and phases) of all the elements of this auxiliary array in accordance with certain criteria to lower the level of side lobe when the interfering signal is received at its direction. The proposed methods offered a reduction in number of side lobes and a greater null depth [9].

Authors in 2003 investigated the performance of LMS and Sample Matrix Inversion (SMI) algorithms. The performance of both algorithms was evaluated using different interference angles, LMS step sizes, and SMI block sizes. According to the results of the simulations, both LMS and SMI are able to cancel out the interference sources even if the interference sources are close to each other. Additionally, the SMI method performs better in terms of null depth than the LMS algorithm [10]. While in 2005, authors proposed adaptive beamforming by integrating the characteristics of the LMS and SMI algorithms since the LMS algorithm is simple to construct and has a low computing complexity. In contrast, SMI has a faster convergence speed than LMS. The numerical results reveal several improvements in convergence, accuracy, and computational efficiency compared to standard LMS and SMI [11].

In 2007, an investigation of Maximum Signal-to-Interference Ratio (MaxSIR) and Minimum Mean Square Error (MMSE) beamforming methods was performed. In both methods, 16 elements of linear array antenna are used. The Simulation results show that both

MaxSIR and MMSE can generate a single beam and provide the same weight and beam pattern. Additionally, both algorithms perform better when the number of elements increases. Also, MaxSIR and MMSE can generate multiple beams, but MaxSIR is less reliable and generate unstable patterns compared to MMSE [12].

In 2009, an effective approach for pattern synthesis of linear antenna arrays was provided in [7]. The suggested technique relies on the LMS algorithm. This study presents a design for implementing the LMS algorithm, which uses an 8 quasi-yagi array and its feeding system.

In 2010 the effectiveness of LMS and NLMS algorithms for mobile communication was examined in terms of NAF and MSE. The simulation results reveal that both algorithms have a good ability in beam formation. Also, it is found that LSM provides better MSE than NLMS; therefore, it is more efficient for mobile communication than the NLMS algorithm [13]. In [14], an adaptive beamforming using LMS was accomplished in 2013. The simulation results show that LMS optimizes the weights, which in turn guide the beam in the desired direction and reduce the interference. Later in 2014, authors investigated several evolutionary algorithms such as LMS, NLMS, RLS, and CM to optimize the weights of smart antenna arrays. Additionally, different types of arrays are considered, such as linear, circular, and planar. The results show that LMS has less convergence speed compared to NLMS, RLS, and CM [8].

Subsequently, in 2013 researchers analyzed the nulling of interference for the adaptive array antenna using LMS. Several parameters are adjusted, such as the array element's phase and beam steering angle. The results show that LMS algorithm can iteratively update the weights to place deep nulls at the direction of the interferers and achieve a maximum in the direction of the desired signal [15].

Authors in 2014 evaluated the performance of the LMS beamforming in two different cases. In the first case, the performance of LMS was measured in terms of Normalized Array Factor (NAF)and Mean Square Error (MSE). The first case results show that the LMS algorithm reaches the converging after 50 iterations, and its error is negligible. While in the second case, different numbers of elements and different distances between the elements were utilized. It was observed that an increase in the number of elements leads to narrow beam width of the array factor and raises the number of side lobes. However, the level of side lobes becomes less than those created by a small number of array elements. At the same time, the overall MSE tends to be practically the same for the given antenna element values [2].

In 2015, an adaptive beamforming optimization was performed using different algorithms. The adaptive algorithms include Least Mean Squares (LMS), Sample Matrix Inversion (SMI), Recursive Least Squares (RLS), and Conjugate Gradient Method (CGM). The performance of beamforming for each method is investigated by altering the element spacing and the number of antenna array elements. The adaptive algorithms were compared in terms of convergence speed, beamwidth, null depths, and maximum sidelobe level. The proposed work observed that CGM has a better convergence speed and greater null depth than other algorithms. It was also shown that an increase in the number of the element can reduce the beamwidth, which in turn leads to more obtained array directional and reeducation in SLL [16]. Authors in 2015 presented the effect of different step size values on beamforming algorithms such as the LMS algorithm, Normalized Least Mean Square (NLMS) algorithm, and Sign Least Mean Square (SLMS) algorithm. It shows that the value of step size has a significant impact on beamforming and proper value is needed for required results [17].

Additionally, researchers in 2018 investigated the performance of the LMS in adaptive beamforming. The performance of adaptive beamforming was analyzed with different spacing between array elements, an increase in the number of array elements, and different array types, such as linear arrays, circular arrays, and planar arrays. The investigation results show that increasing the spacing between the elements and the number of elements leads to a narrower beamwidth. It was also observed that the LMS algorithm with a planar array resulted in a narrower beamwidth than other array types. [1].

Also, authors in 2018 examined several adaptive beamforming optimizers such as non-blind LMS, blind CMA, and Practical Swarm Algorithm (PSO). The adaptive beamforming generates different weights to improve the radiation pattern to direct the main beam in the desired direction and place null in the interference signal. The average SLL and directivity were also investigated, and the results indicated that PSO performs better than other algorithms [3].

In 2019, researchers proposed improving the LMS algorithm called a Fractional LMS (FLMS). The main objective of FLMS was to adjust the weights of the uniform circular array, and its result was also compared with LMS. It is shown that FLMS gives better performance in terms of convergence speed and side lobe [18].

In 2020, researchers proposed the VSS-LMS algorithm for adaptive beamforming. VSS-LMS uses a variable step size based on the normalized sigmoid function. The variable step was determined by utilizing the mean of instantaneous error and then normalized by the squared cumulative sum of instantaneous error and predicted signal power. It was observed that the proposed algorithm could determine the step size value adaptively without changing any other parameters [19].

In 2021, adaptive beamforming based on the LMS algorithm was proposed. The adaption is implemented only on the array elements located in the center, while other elements are kept uncontrollable. Different algorithms for adaptive beamforming were utilized, such as Least Mean Square (LMS), Recursive Least Square (RLS), Sample Matrix Inversion (SMI), Conjugate Gradient (CG), and Constant Modulus (CM). The performance of proposed method shows different improvements in term of convergence speed and less complexity as compared to the standard method [20].

In 2021, a Uniform Linear Array (ULA) was modified by placing the first and the last elements at the top and bottom of the array axis. For adaptive beamforming, the VSSNLMS algorithm is utilized. The simulation results were compared to the well-known LMS and NLMS beamformers. The proposed method shows better convergence rate and data rate in comparison to LMS and NLMS [21].

1.3 Problem Statement

In recent years, the large scales of wireless applications resulted in a crowded spectrum problem and thus called the researchers to study the possible solutions for the 5G and beyond wireless communication systems [22]. Both Multiple Input Multiple Output (MIMO) and massive MIMO antenna arrays with adaptive beamforming capability have been recommended as an efficient solution for current and future wireless communication systems. One of the most challenging issues in these mobile systems is the interfering signals that may originate from the nearby cells that reuse the same frequency as that of the covered base station. Suppressing the interfering signals in such systems can be achieved by adequately reshaping the array patterns of the antenna arrays by steering the desired nulls into directions of undesired interfering signals to improve the signal to interference plus noise ratio (SINR) at the system output. Generally, reshaping array patterns can be synthesized by five main array design parameters [4,22] which they are the geometrical layout of the array elements (i.e, linear, circular, and planar), and the separation distances between their elements, the excitation amplitude and phase of the individual elements and finally the elemental beam pattern. These design parameters have been utilized by many analytical [23] or numerical array synthesis techniques [5, 24].

Numerical techniques employ an adaptive optimizer to improve and optimize the array patterns in an online processing manner which can directly account for any changes in the directions of the interfering signals [25]. Such adaptive optimizer forms a vital part of the 5G wireless communication systems to adaptively upgrade the array amplitudes and phases to track any changes in the environment. Accordingly, the demand array patterns can be reformed based on steered nulls. In the literature, subarray weighting techniques were performed at the array elements level, where the array elements are divided equally or unequally into a certain number of subarrays, for example, in [26, 27] such synthesis techniques are usually associated with some undesirable distortions in their array patterns since the obtained patterns were not subject to any constraints during the synthesis process.

1.4 Objectives

The objectives of this research are:

1. To design an adaptive antenna arrays with simplified array weighting configurations to make it easier in practical implementation. Moreover the adaptive array should be able to adaptively suppress the undesired interfering signals. Further, it is intended to accelerate the adaptive controller of the antenna array in order to improve the convergence speed, which is a very important factor in practice for better tracking of environmental changing. All of these advantages should be obtained under a satisfactory performance of the used antenna array.
2. To study various array configurations in the excitation weighting network and propose some new configurations that is competitive.
3. To simulate the proposed array designed configurations using MATLAB simulation and CST full wave simulators. Also to measure the radiation pattern of the designed array antenna to verify the idea. In simulation, the performances of the considered antenna arrays in terms of beam pattern, excitation weights, Mean Square Error (MSE), and the Signal to Interference plus Noise Ratio (SINR) have been studied and compared.

4. To suggest most efficient array weighting configurations that enjoys simplicity in its construct stage and still performs well.

1.5 Research Aim

This research aims to investigate various adaptive array configurations that help to simplify the design of the array feeding network. At the same time makes the adaptive controller of the antenna array faster by changing the weights of the array elements to cope with environmental changes. Many other advantages can be shown which make the large arrays easy to be implemented in practice for 5G and beyond applications.

CHAPTER TWO

BACKGROUND THEORY

2.1 Introduction

Wireless communications system designers and engineers have made an effort to address issues including co-channel interferences, multipath fading, and Inter-Symbol Interference(ISI). These challenges are all major issues that reduce the qu ality of service and restrict the number of subscribers that can be provided by a system [28]. If two or more signals with the same frequency reach the receiver at the same time, the interference known as co-channel interference can occur. This interference occurs because of the re-assignment of similar spectrum bands to other distant cells, resulting in unwanted signals mixed in with the desired ones [29].

It has been proven that classic methods such as Omni-directional and diversity systems are insufficient for today's wireless systems and the requirement to lessen infrastructure and maintenance expenses. Because of the interference initiated by multiple tracks of signal reception, known as multipath fading, the system's performance is also affected and getting worse [24]. Only smart antenna systems, which have gone through numerous rounds of research before becoming commercially accessible, take advantage of this issue to increase reception by applying direction spatial processing, which sets this system excluding the rest [30]. The development of algorithms for "smart antenna systems," which can regulate power, improve quality of service, and increase capacity, has been a major focus of current research efforts. As a result of its increased capacity and enhanced data rate, this system outperformed traditional ones in terms of spectral efficiency, allowing it to serve more subscribers while also expanding its coverage area.

2.2 Concept of Smart Antenna

The hardware section of a smart antenna system is made up of an array of antennas, also known as an antenna array, while the digital signal processing unit serves as the brains of the system [28]. Beamforming algorithms have been developed in recent years as means of directing the main beam of the antenna toward the desired target and avoiding unwanted nulls in other directions. The beamforming would greatly reduce noise and increase antenna directivity, as the antenna directs its main beam toward the desired direction and place nulls in other directions [31].

Smart antenna systems may be introduced as smart technologies that can increase the gain of antenna array systems while minimizing interference, boosting the quality of service and the performance for the system, and attaining spectral efficiency.

2.2.1 Analogy for Adaptive Smart Antenna

The human brain is often used as a model for many intelligent systems that attempt to approximate human processes, and this was the case with the smart antenna system as well.

Researches show that humans can recognize and locate a certain sound even while other speakers or sound sources are moving around them. For this reason, it can be argued that ears are like radiation elements in an antenna array. At the same time, the brain operates as software in a smart antenna system by calculating the delay time between the two ears to find the target speaker [32]. The two ears and the brain work together to create a system that can locate and suppress other voices in a dark room and simultaneously receive and transmit signals in an adaptive spatial manner and this is similar to the concept of a smart antenna system that can receive and transmit signals in an adaptive spatial way, while simultaneously maximizing reception toward the target and minimizing interfering signals [33]. The blindfolded guy in a dark room with two speakers in the analogy for the adaptive smart antenna is shown below in Figure 2.1.

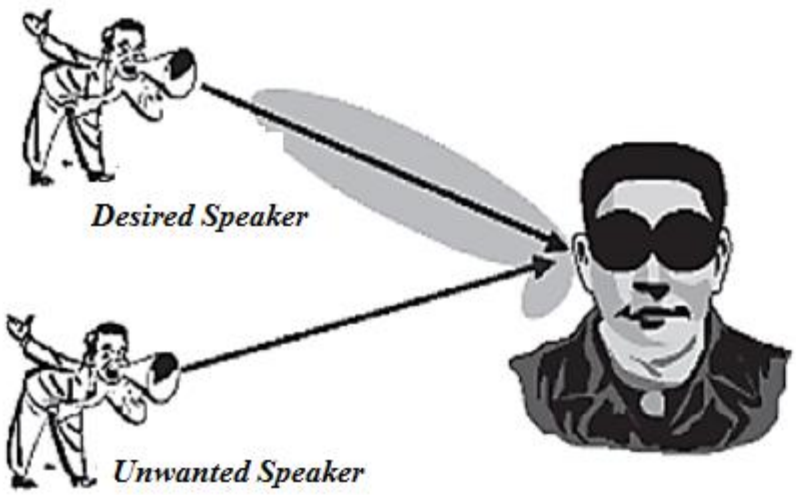


Figure 2.1. Smart antenna analogy [33].

2.3 Smart Antenna System Categories

A smart antenna system's capacity to increase service quality and decrease interference is defined by its ability to evaluate the system's performance based on the kind of antenna array used. The following are the categories of smart antenna and their comparison in term of levels of intelligence, structural, and performance.

2.3.1 Switched-beam System

Beam switching is the simplest method for implementing smart antennas. This system employs a dynamic cell-sectoring strategy defined by fixed, predetermined lobe patterns as shown in the Figure 2.2. Due to its ability to transition between many fixed beams, generated by phase adjustment only, dependent on the user's direction and movement. In order to increase gain, these systems can surpass "sectorized antenna systems" in terms of their capacity to choose the proper beam and achieve directivity without requiring a set of metallic physical designs [28].

Despite the system's ability to reduce interferences, it is unable to totally eliminate them. Therefore, it cannot achieve maximum gain if the user is not in the center of the primary beam [31].

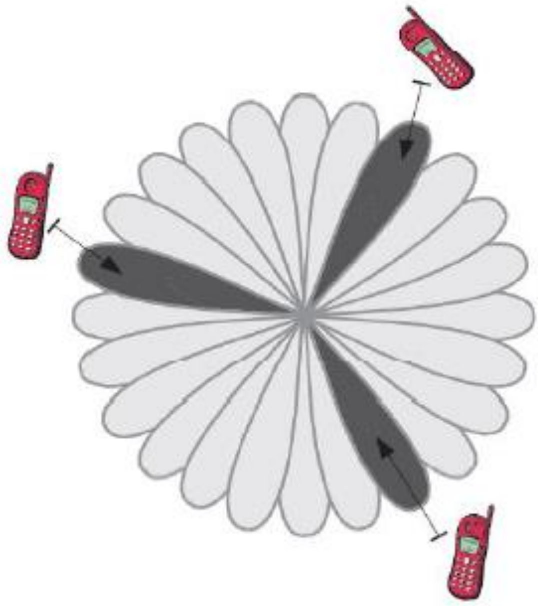


Figure 2.2. Switched-beam coverage pattern [33].

2.3.2Adaptive Arrays System

Adaptive array systems are considered as the most intelligent smart antenna systems due to their capacity to alter their radiation pattern in real time. In order to place null in all undesirable directions, this system tracks the Signal of Interest (SOI) by using the spatial signal signature to predict the position of the intended user. Additionally, this technique utilizes a signal processing unit that modifies the system's parameters in real-time to enhance performance.

The adaptive array coverage pattern may adjust the radiation pattern for each unique target in the system and insert nulls in interference directions, and providing a great degree of freedom, as illustrated in Figure 2.3.

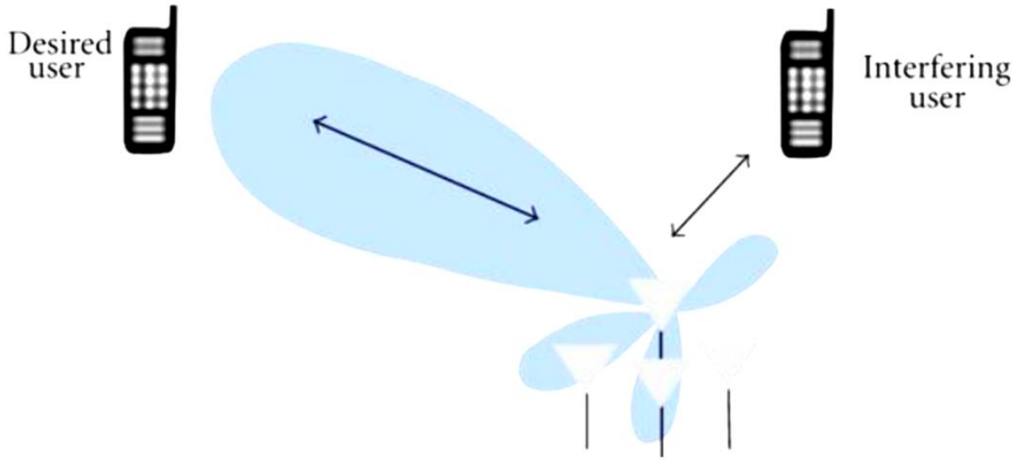


Figure 2.3. Coverage of adaptive array

The ability to form the main beam is the major differentiator between adaptive antenna and switched-beam antenna systems. The adaptive array system has the ability to regulate the phase and the amplitude of radiation patterns to obtain optimal gain in the intended direction and to reduce other interferences. In contrast, the second method is limited to selecting the suitable fixed beam and switching between predetermined beams based on the circumstances. On the other hand, the adaptive array system is more complicated and costly [34].

2.4 Architecture of Smart Antenna System

Typically, a smart antenna system comprises an antenna array, a radio unit, and a software component. The subsection that follows describes in depth the components of an adaptive system.

2.4.1 Antenna Array

The antenna array is a group of "antenna" sensors with the same orientation and radiation pattern which are all connected and used to send or receive signals [32]. Since the elements of this array are connected to the signal processing unit, it mostly affects the shape of the radiation pattern in adaptive systems [31]. These elements of the antenna array are arranged so that there are no variances in the received signal amplitude. Additionally, the number of antennas must be the minimum number of required for designed system in order to avoid complexity.

2.4.2 Geometry of Antenna Arrays

Types of antenna arrays are varied according to the geometrical arrangement of elements for example the term "uniformly spaced" refers to an antenna array in which adjacent elements are separated by identical spaces; whereas, the term "non-uniformly spaced" refers to an antenna array in which the distances between adjacent elements are irregular spaces [35]. Moreover, the radiation pattern is influenced by the separation of the elements. The beamwidth decreases as the space between the elements increases. Figure 2.4 shows four different types of arrays, including circular, planner, and uniform linear arrays [22], [32], whereas (a) represents a uniform linear array with one-dimensional beamforming, (b) is a uniform circular array, (c) shows two-dimensional beamforming in both azimuthal and elevation angles.

The Figure 2.4 (d) illustrates a cubic array with Δx, Δy, and Δz separation. This structure can be represented as a three-dimensional array.

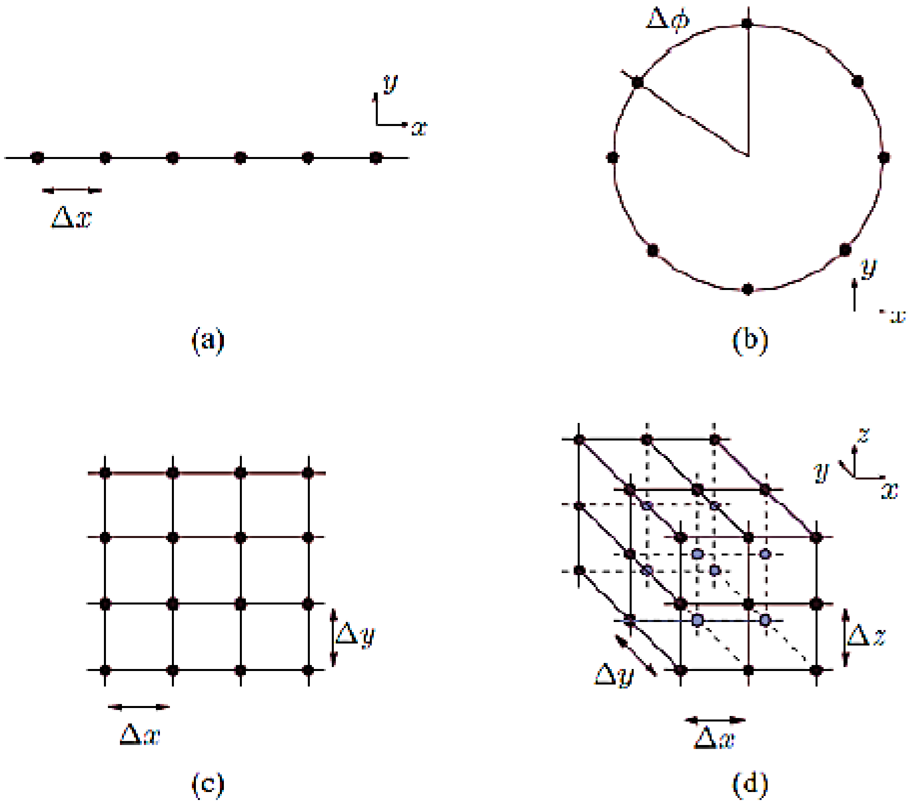


Figure 2.4: Four distinct array types [38].

2.4.3 Radio Unit

For a smart antenna system, a radio unit must have the necessary down/up converters to convert radio signals into low-frequency signals to be processed [35]. The required total number of converters should be the same as number of array elements in the antenna array. Figure 2.5 depicts the block of the hardware component consisting of antenna parts that receive signals and inject them into a low-noise amplifier that amplifies a very low-power signal without altering its signal-to-noise ratio. The second component of the hardware is a down/up converter, and the last component is an analog-to-digital block that digitizes the signal before its preparation for digital signal processing.

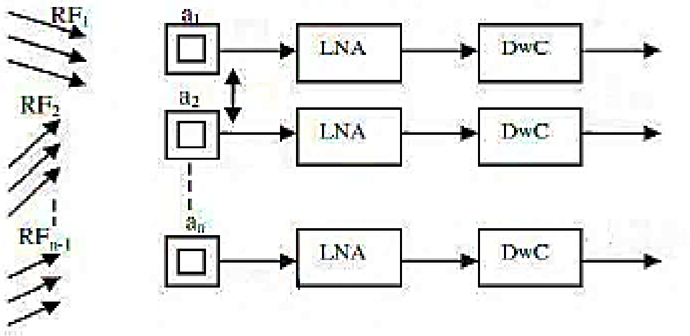


Figure 2.5. Radio unit for smart antenna [37].

2.4.4 Signal Processing Unit

The primary function of the signal processing unit in an adaptive system is to improve performance and turn it into a smart system. This system collects data to derive knowledge, which is then applied using algorithms for adaptive signal processing [31]. Additionally, signal processing is responsible for identifying the location of the signal after it has been captured, trucking it in order to maximize reception in the desired direction, and removing out the interferences from undesirable directions. This process is carried out via the DOA estimator and adaptive beamforming.

2.4.5 Direction of Arrival (DOA)

The DOA is a method that uses the delays between elements in an array to make estimations about the direction of the analog arrival of received signals. In the beginning, the signals in the array are correlated, then the eigen analysis and and signal noise subspace formation are performed [31].

DOA estimation strategies seek to construct a function that indicates the angles of arrival based on maxima versus angle. This function is typically referred to as the pseudo spectrum, and its units can be expressed in energy or watts. There are alternative strategies for defining the pseudo spectrum. Generally, the DOA estimating methods may be divided into four groups: traditional, subspace, maximum likelihood, and integrated techniques [35].

2.5 The Goal of Smart Antenna

The smart antenna system has made a big change in the communication world because it can solve problems and has features that make it better than other wireless systems. The following are the features of smart antenna

2.5.1 Expanding the coverage

Due to the fact that the smart antennas are more directing with comparison with other conventional systems such as omnidirectional antennas or sectoring systems, they can achieve superior coverage. The coverage area is defined where communication between a user and the base station is accessible. In addition, it proved that the smart antennas provides coverage that is (N) times more than the traditional systems. In contrast, the number of base stations required has been lowered by (1/N) when employing a smart antenna system with N antenna elements [36]. Additionally, It is important to note that the directivity of smart antenna systems reduce the amount of power for mobile devices, hence extending battery life [31].

2.5.2 Increasing Capacity

Interference rejection helps the system to enhance the signal-to-interference, which in turn increases the capacity of the system and the total number of subscribers [31].

2.5.3 Enhancing bit-rate

A smart antenna system is able to minimize the delay spread of the channel, reject multipath, and maintain the bit rate. Since smart antenna system utilizes the spatial variation of the signals in order to reject signals originating from multipath by employing an equalizer to recover the signal which in turn enhance the bit rate.

2.5.4 Security

In communication systems, security is considered a critical issue. The smart antenna system has the ability to avoid intruding on users' network data as the transmission of signals is not in all directions which results in reducing the likelihood of data snooping and increasing security [33].

2.6 Adaptive Beamforming

Adaptive beamforming employs antenna arrays and powerful signal processing to autonomously modify the beam pattern in response to changing signal conditions. Creating a beam in the desired direction while canceling the pattern in the interference direction. The desired radiation pattern is obtained by continually multiplying the incoming signal with complex weights and then adding them together. These weights are calculated using various adaptive beamforming approaches. As a result, adaptive algorithms are essential for adaptive beamforming [16,37].

The outputs of antenna elements are combined in an adaptive antenna array. The antenna's directional gain is regulated by either controlling the phases and amplitudes, or both at each element. The weighted signals are added together, and the result is sent to a controller. To respond to changes in the signal environment, these complex weights are calculated adaptively [3]. Weights in the adaptive antenna are adaptively adjusted using different algorithms, resulting in an output beam pattern optimal for system enhancement [8]. The adaptation is accomplished by multiplying the incoming signal by complex weights and then summing them to generate the desired radiation pattern, as seen in the Figure 2.6.

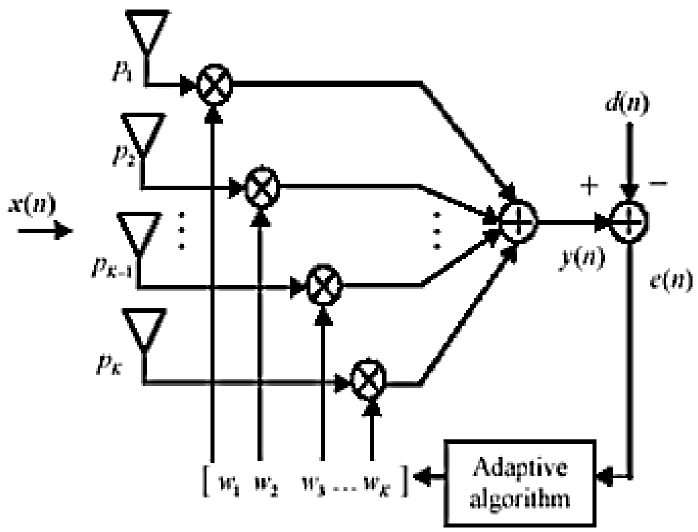


Figure 2.6: The structure of adaptive antenna [9].

The complex weights are computed using various algorithms such as LMS, CM, RLS, and SMI. The algorithms are used in beamformer optimization to reduce interferences, side-levels, and noise. Most popular optimization algorithms are discussed in the following subsection

2.6.1 Recursive Least Square (RLS)

RLS is a well-known adaptive beamforming technique based on recursive least square. This approach does not require matrix inversion because the correlation matrix is immediately determined. The summation of squared errors for the inputs is used to update the complex weights in place of the mean square error minimization. The initial adaption of this technique was developed for the Kalman filter to be used in multi-tap transversal filtering with variable time frame sampling. Nonetheless, this approach applies to various systems with inputs derived from distinct sources. During adaptation, the algorithm employs the required signal and correlation matrix [38].

2.6.2 Constant Modulus (CM)

The Constant Modulus method is a blind algorithm due to the absence of the desired signal. Each round of the algorithm involves the execution of three separate stages. In the initial phase, the processed signal is computed using real weights. The second step consists in generating an error from the calculated signal. In the last stage, the weights are updated with fresh error data [38].

2.6.3 Least Mean Square (LMS) Algorithm

The LMS algorithm, developed by Widrow and Hoff in 1959, is an adaptive algorithm that employs a gradient-based steepest descent strategy.

The LMS algorithm runs with prior knowledge about the signal's direction of arrival and spectrum but no knowledge of the noise and interference in the channel. It takes advantage of the given data to estimate the gradient vector. LMS includes an iterative technique that makes successive modifications to the weight vector in the direction of the gradient vector's negative, resulting in the minimum mean square error. A least mean square algorithm adaptive beamforming system comprises several antennas, complicated weights that amplify (or attenuate) and delay the signals from each antenna element, and a summer that adds all of the processed signals to tune out the signals of interest, as shown in Figure 2.7.

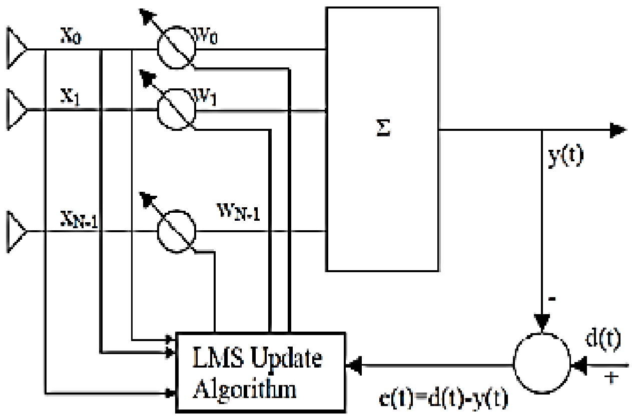


Figure 2.7. Adaptive antenna based on LMS

Because certain incoming signals from specific spatial directions are filtered out while others are amplified, thus, it is frequently referred to as spatial filtering. The incident waves in the narrow band are known as s(t).

$s(t)= A \exp(2\pi f_c t + \varphi)$ [2.1]

A: defines the signal amplitude, f_c is the carrier frequency, φ: phase difference between incoming waves at consecutive elements $=(2\pi/\lambda)\, d\sin(\theta)$, *d*: is the distance between successive antenna phase centers in the array, and θ is the angle of arrival w.r.t normal. [1]

The waves are transformed to electrical signals x(t) when they reach the antenna elements. The input signals are denoted as

$x_0(t), x_1(t), \ldots\ldots\ldots x_{N-1}(t)$. [2.2]

$$x_i(t) = \begin{bmatrix} 1 \\ \exp(-jkd\sin(\theta)) \\ \vdots \\ \vdots \\ \vdots \\ \exp(-jk(N-1)dsin(\theta)) \end{bmatrix} s(t) \qquad [2.3]$$

$$x_i(t)=a(\theta)s(t) \qquad [2.4]$$

Where N is the number of antenna elements and a(θ) is the steering vector that governs the antenna beam's direction. For adaptive beamforming, each element's output $x_i(t)$ is multiplied by weights $w_0, w_1, w_2, \ldots\ldots w_{N-1}$, which adjust the phase and amplitude of the incoming signal correspondingly. These weighted signals are added together to produce output. The antenna array's output signal y(t) is thus given by [1].

$$y(t)=\sum_{i=0}^{i-1} x_i(t) w_i \qquad [2.5]$$

$$y(t) = [w_0 \;\; w_1 \;\; .. \;\; .. \;\; w_{N-1}] \begin{bmatrix} 1 \\ \exp(-jkd\sin(\theta)) \\ \vdots \\ \vdots \\ \vdots \\ \exp(-jk(N-1)dsin(\theta)) \end{bmatrix} s(t) \qquad [2.6]$$

$$y(t)=w_i\, x^T(t) \qquad [2.7]$$

The error e(t) between a desired signal d(t) and the array output y(t) is then minimized using an adaptive technique . By altering the weight vector, the entire antenna design is continually updated. This is a classic Weiner filtering problem for which the LMS method may be used to iteratively find a solution.

Therefore, the LMS algorithm can be summarized in following equations.

Output: $y(n)=w^H(n)\,x(n)$ [2.8]

Error: $e(n)=d(n)-y(n)$ [2.9]

Weight ,$w(n+1)=w(n)+\mu e^*(n)x(n)$ [2.10]

Step size (μ) is considered as 1/(real(trace(Rx))). [2.11]

The radiation pattern of the linear array for far field is represented in terms of array factor (AF) . The array factor is given by

$$AF=\sum_{n=1}^{N} w(n)\exp(j(n-1)(kd\sin(\theta))) \quad [2.12]$$

The knowledge of the received signal eliminates the need for beamforming, but the reference can also be a vector that is partly known or correlated with the received signal [39].

To arrive at the optimal weight values, the LMS algorithm employs the steepest descent approach. However, this method must undergo several rounds before reaching convergence. The Least Mean Square algorithm's convergence speed is determined by the step size (μ) and the correlation matrix. In a dynamic channel environment, it converges slowly due to the dispersion of eigenvalues. The normalized least mean square and recursive least square methods tackle this problem [8].

Because it employs a training or reference signal, the LMS algorithm is a form of the non-blind algorithm. During the training time, the training signal is sent from transmitter to receiver. It employs a gradient-based steepest descent algorithm. It uses an iterative technique to make successive corrections to the weight vector in the gradient vector's negative direction, resulting in the minimum mean square error. The LMS algorithm is quite straightforward; it does not need the computation of correlation functions or matrix inversions [24 [2].

The LMS algorithm is often called the Stochastic Gradient Descent (SGD). It is a straightforward beam-producing technique. Because the channel in a wireless connection changes over time, the weight vector must be adjusted regularly; therefore, using the Minimal Mean Square Error (MMSE) or Least Square (LS) approach is not recommended. As a result, LMS utilizes the previous weight to generate the next weight set. LMS is a gradient-based beam forming technique that uses a repeating procedure to produce consecutive adjustments in the negative gradient direction, resulting in the smallest MSE [40].

LMS technique is a straightforward adaptive beamforming algorithm that works well in continuous transmission networks. The LMS algorithm is notable for its simplicity; it does not need measurements of the relevant correlation functions or matrix inversion. The LMS algorithm was driven by three primary factors: μ, the number of weights and the Eigen-value of the correlation matrix of the input vector data [11].

CHAPTER THREE

ADAPTIVE ARRAY CONFIGURATIONS

3.1 Introduction

This section presents and discusses the proposed adaptive array configurations. The proposed configurations are comprised of three configurations. The first configuration presents a regular fully adaptive subarray, which aims to reduce the complexity and mean square error. The regular subarrays are formed by dividing all the array elements into several subarrays and each subarray contains equal number of elements.

Subsequently, the second configuration is partially adaptive elements that aims to more reduction in complexity and mean square error. The main different between fully adaptive subarray and partially adaptive elements is that in partially adaptive elements only a certain number of the array elements are chosen to be adaptive. In contrast, the remaining elements are made constant.

Finally, the third configuration is partially adaptive irregular subarray, which aims to achieve more reduction in the feeder complexity and maintain good performance for interference suppression. The configuration of the third approach is achieved by dividing the partially adaptive elements into smaller partially adaptive subarrays**.** Furthermore, the outcomes of all three approaches mentioned above are developed to reduce the feeder complexity, improve the algorithm's convergence speed, and maintain good interference suppression performance.

The three design configurations during this research are modeled and simulated in order to verify the effectiveness of the proposed configurations. Furthermore, The three configurations in this research are discussed in the following section.

3.2 Regular Fully Adaptive Subarray

In this proposed configuration, regular subarrays are formed by dividing all the array elements, N, into several equal subarrays, Q, and each subarray, q, contains M elements. Note that M is always less than N, and N should be even so that the remainder of the division $Q=N/M$ is always an integer number. Figure.3.1 shows the configuration of the proposed regular fully adaptive subarray. For N=12 elements and to get equal subarrays, the value of M in each subarray may contain any of the following numbers: 2, 3, 4, and 6. Note that as the number of elements in the subarray, M, increases, the complexity of the feeder decreases, the shape of the obtained radiation pattern may encounter more distortion. Thus, the tradeoff between the complexity and the array pattern shape should also be considered.

The array factor of such subarray is calculated as follow

$$AF_{\text{subarray}}(\theta) = \sum_{q=1}^{Q} \sum_{m=1}^{M} w_{q_m}^{H} \ e^{j(q_m-1)\frac{2\pi}{\lambda}d\sin(\theta)} \qquad [3.1]$$

While, the equation of updating weight is written as following

$$\overline{w_{sub}}(k+1) = \overline{w_{sub}}(k) + \mu\, e^{*}(k)\bar{x}(k) \qquad [3.2]$$

$$\overline{w_{sub}} = [w_1 w_2 \ldots . w_Q]^T \qquad [3.3]$$

These subarray weights are updated adaptively during the adaptation process of the LMS algorithm. Note that the number of the adaptive elements has been reduced from N to only Q where $Q < N$ which improves the optimizer's convergence speed.

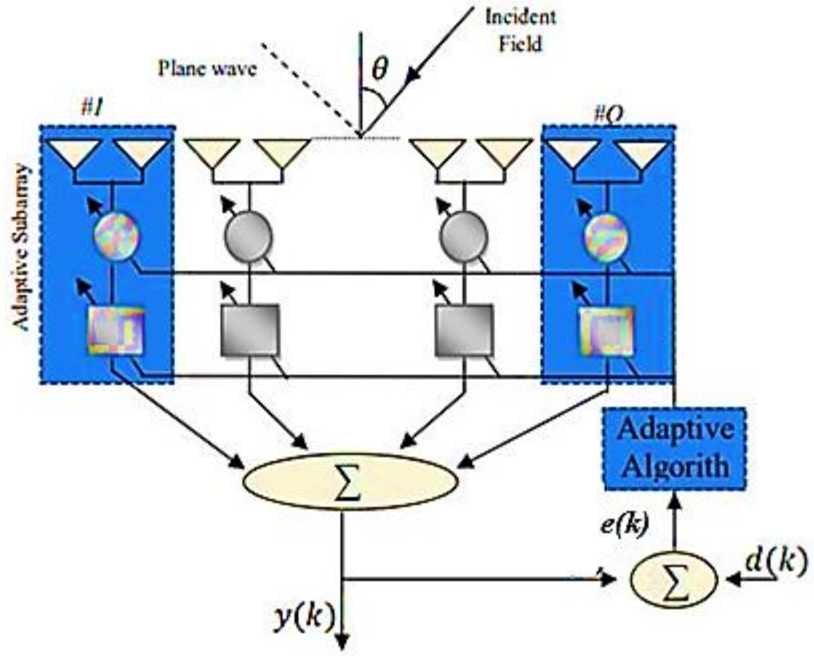


Figure 3.1. Fully adaptive subarray configuration

3.3 Partially Adaptive Elements

The second proposed configuration is the partially adaptive elements where only a certain number of the array elements are chosen to be adaptive, while the remaining elements are made constant as shown in Figure.3.2 Let's assume that the number of the adaptive elements is *P*, thus the number of fixed elements is *N*-*P*. *P* should be chosen to be smaller than *N* and it should also sufficient enough to steer the desired nulls, then both the complexity and the interference cancellation can be improved. The array factor of such configuration can be written as following

$$AF_{partially}(\theta) = \underbrace{\sum_{n=1}^{N-P} e^{j\left(\frac{N-P}{2}\right)\frac{2\pi}{\lambda}d\sin(\theta)}}_{constant\ element} + \underbrace{\sum_{p=\left(\frac{N+P}{2}\right)+1}^{N} \left\{ w_p^H e^{j(p-1)\frac{2\pi}{\lambda}d\sin(\theta)} \right\}}_{adaptive\ element} \qquad [3.4]$$

As seen from this equation, the feeder complexity was reduced from N to only P adaptive elements where $P < N$. The adaptive weight vector can be written as

$$\overline{w_{partially}}=[w_1\ w_2\ \dots .\ w_p]^T \qquad [3.5]$$

Here, the value of P can be pre-specified by the designer to compromise feeder complexity and finer radiation pattern.

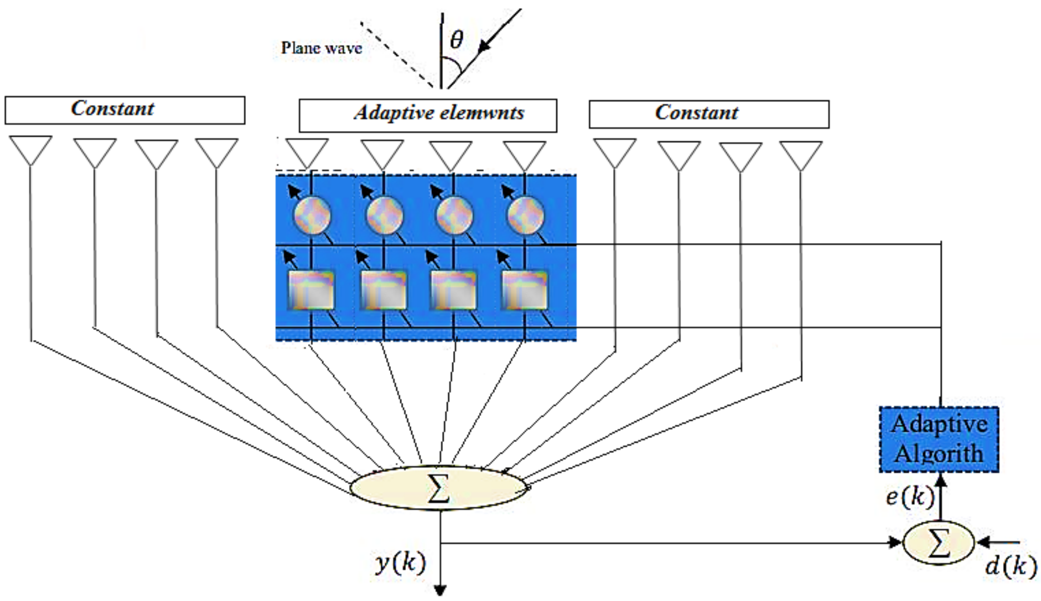


Figure 3.2. Partially adaptive array configuration.

3.4 Partially Adaptive Irregular Subarray

As mentioned in the previous section, the main array elements are partitioned into adaptive and fixed elements. The adaptive elements, P, can be further divided into smaller partially adaptive subarrays to achieve more feeder complexity reduction, improve the convergence speed of the algorithm, and maintain good performance for interference suppression. However, to keep a good beam pattern shape without distortion, especially in desired null directions, the number of the created subarrays should be equal to or more than the total number of the interfering signals. The proposed configuration is shown in Figure 3.3.

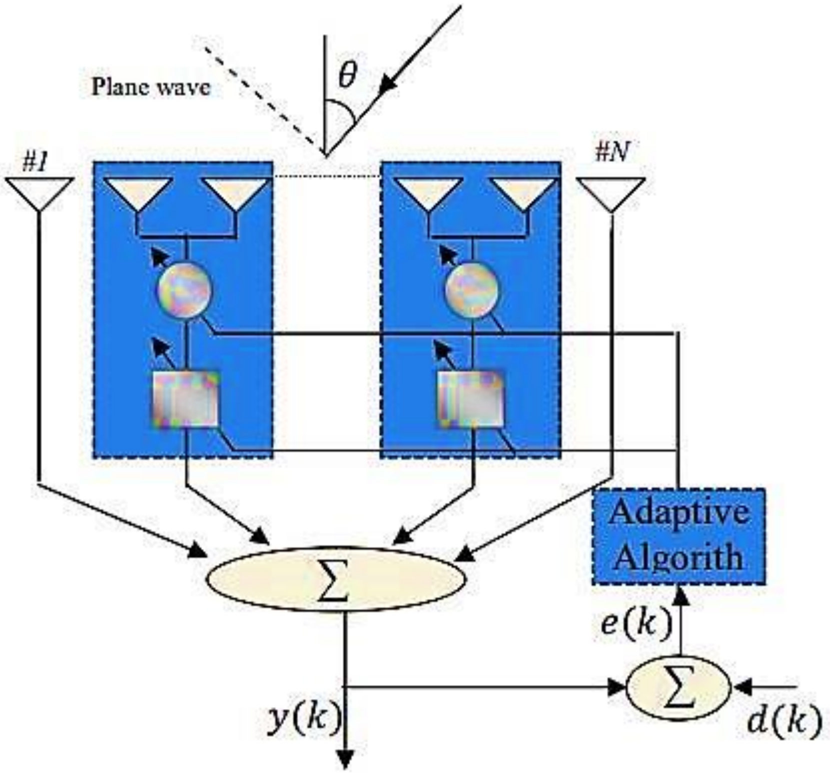


Figure 3.3. Partially adaptive subarray configuration.

3.5 Modeling and Simulation

In this section, the simulation software, simulation setup, and performance parameters are explained. The simulation results and discussion of the proposed configurations are presented in section 3.6.

3.5.1 Simulation Software

In the simultion, MATLAB software is used to implement the proposed approaches to evaluate the performance of all the proposed approaches. Since it contains complicated data structure, built-in editing, debugging tools, and support object-oriented programing. Making MATLAB an excellent tool for teaching and research.

3.5.2 Simulation Setup

This section presents the default simulation setup used to measure the performance of the proposed approaches. the default simulation parameters chosen in this study are summarized in table 3.1.

Table 3.1. Simulation Parameters**.**

parameter name	Value
number of element	12,40,80
Step size for 12 elements	0.006
Step size for 40 elements	0.0125
Step size for 80 elements	0.02
interelement spacing	0.5λ
desired signal direction	0°
interfering signals directions	−45°,25°
number of iterations	100
noise variance	0.0001
signal variance	0.001
interferer 1 variance	0.5
interferer 2 variance	0.5

3.5.3 Performance Parameters

To determine the efficiency of the proposed approaches against the specified objectives, the following performance parameters are used, as listed in the following subsection.

3.5.3.1 Minimum Mean Square Error

Mean Square Error (MSE) is the difference between the array output and the reference signal. Minimum Mean Square Error (MMSE) minimizes the error while iterating the array weight. An alternative means for optimizing the array weights is found by minimizing the MSE. Figure 3.4 shows the MSE adaptive system.

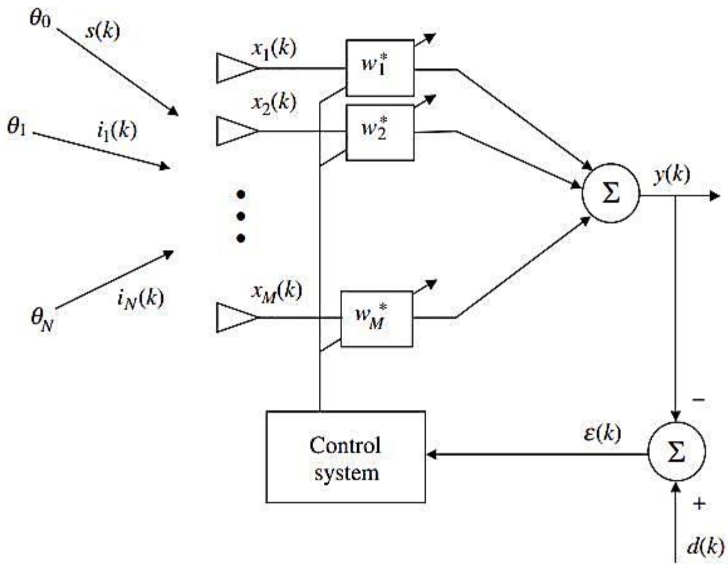


Figure 3.4. MSE for the adaptive system [31].

The reference signal is the d(k) signal. the reference signal is preferably either identical to the desired signal s(k) or substantially correlated with s(k) while being uncorrelated with the interfering signals in the system $i_n(k)$. If s(k) is not distinguishable from the interfering signals, the minimal mean square method will not function correctly. error signal is the signal such that ε(k) [31].

$$\varepsilon(k) = d(k) - \bar{w}^{h}\ \bar{x}(k) \qquad [3.6]$$

It can be demonstrated by some elementary algebra that the MSE is given by the following [41].

$$|\varepsilon(k)|^2 = |d(k)|^2 - 2d(k)\ \bar{w}^{h}\ \bar{x}(k) + \bar{w}^{h}\ \bar{x}(k)\ \bar{x}^{h}(k)\ \bar{w} \qquad [3.7]$$

3.5.3. 2 Maximum Signal to Interference Plus Noise Ratio

Maximizing the Signal to Interference Plus Noise Ratio (SINR) is one criterion that may be used to improve the received signal and reduce interference and noise signals. If we can eliminate all interference and noise by placing nulls at their angles of arrival, the SINR will be maximized automatically. From Figure 3.5, it can be noticed that the certain number of elements and a number of desired signal with a number of interference signal [31]. The array output y may be expressed as follows [41].

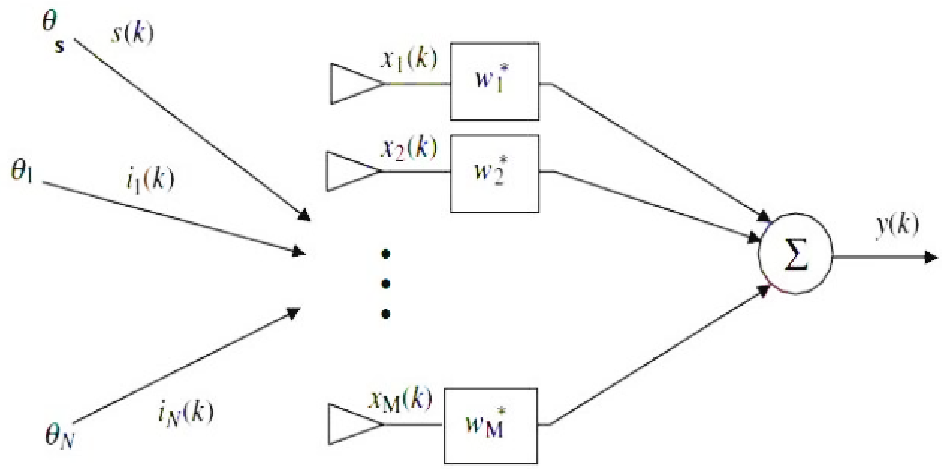


Figure 3.5. M number of elements with number of desired signal and interference signal [31].

$$y(k) = \bar{w}^H \cdot \bar{x}(k) \qquad [3.8]$$

where

$$\bar{x}(k)=\bar{a}_0\, \bar{s}(k)+[\bar{a}_1\, \bar{a}_2 \ldots\ldots \bar{a}_I]\begin{bmatrix} i_1(k) \\ i_2(k) \\ \cdot \\ \cdot \\ \cdot \\ i_I(k) \end{bmatrix} + \bar{n}(k) \qquad [3.9]$$

$$= \bar{x}_s(k) + \bar{x}_i(k) + \bar{n}(k) \qquad [3.10]$$

With

$$\bar{w} = [\bar{w}_1 \bar{w}_2 \cdots \bar{w}_M]^T = \text{array weights} \qquad [3.11]$$

$\bar{x}_s$(k) = desired signal vector

$\bar{x}_i$(k) = interfering signals vector

$\bar{n}$(k) = zero mean Gaussian noise for each channel

$\bar{a}_i$ = M-element array steering vector for the θi direction of arrival

We may rewrite Eq:[3.8] and Eq.[3.10] to get

y(k) = $\bar{w}^H \cdot [\bar{x}_s(k) + \bar{x}_i(k) + \bar{n}(k)] = \bar{w}^H \cdot [\bar{x}_s(k) + \bar{u}(k)]$ [3.12]

where

$\bar{u}(k) = \bar{x}_i(k) + \bar{n}(k)$ = undesired signal [3.13]

The calculation for both the desired signal ($\bar{R}_{ss}$) and the undesired signals ($\bar{R}_{uu}$) for array correlation matrices and the formula for the weighted array output power for the desired signal are as follow:

$\sigma^2{}_s = E [|\bar{w}^H \cdot \bar{x}_s|^2 = \bar{w}^H \cdot \bar{R}_{ss} \cdot \bar{w}$ [3.14]

Where

$\bar{R}_{ss} = E [\bar{x}_s \bar{x}_s^H]$ = signal correlation matrix [3.15]

The weighted array output power for the undesired signals is given by

$\sigma^2{}_u = E [|\bar{w}^H \cdot \bar{u}|^2] = \bar{w}^H \cdot \bar{R}_{uu} \cdot w$ [3.16]

where it can be shown that

$\bar{R}_{uu} = \bar{R}_{ii} + \bar{R}_{nn}$ [3.17]

With

$\bar{R}_{ii}$ = correlation matrix for interferers

$\bar{R}_{nn}$ = correlation matrix for noise

The SINR is the ratio of desired signal power to undesired signal [41].

$$\text{SINR} = \frac{\sigma^2{}_s}{\sigma^2{}_u} = \frac{\bar{w}^H.\bar{R}_{ss}.\bar{w}}{\bar{w}^H.\bar{R}_{uu}.\bar{w}} \qquad [3.18]$$

3.5.3. 3 Weights

The combination of each antenna's relative amplitude and phase shift is known as its complex weight. Various algorithms are used to determine these weights. The LMS adaptation process starts updating the complex weights in terms of amplitudes and phases with respect to the iteration number. The initial values of the amplitude weights are assumed to start from zero and are gradually adjusted according to the LMS sense until reaching their optimum final values.

The adaptation process of the complex array weights (amplitude and phase) are based on least mean squares as follows

$$\bar{w}(k+1) = \bar{w}(k) + \mu\, e^{*}(k)\, \bar{x}(k) \qquad [3.19]$$

Where $\bar{w} = [w_1\ w_2\ \ldots\ .\ w_N]^T$ are the complex weights, μ is the step size of the adaptive algorithm, k is the discrete time, $\bar{x}(k)$ is the overall input signals

3.5.3. 4 Array Factor

The antenna array includes adaptive beamforming algorithms for identifying, tracking, and mitigating interference. By combining the signals incident on the linear antenna array and knowing their arrival directions, it is possible to optimize the radiation pattern by adjusting a set of weights. A smart antenna has the ability to focus its radiation beam toward the desired user while reducing the beam pointed toward the undesired user and rejecting interference [31]. The beam pattern of the designed array can be found by

$$AF(\theta) = \sum_{n=1}^{N} w_n^H\, e^{j(n-1)\frac{2\pi}{\lambda} d \sin(\theta)} \qquad [3.20]$$

3.6 Simulation Results and Discussion

To verify the effectiveness of the proposed adaptive array configurations, various numbers of numerical results have been presented and compared. The performance of the proposed configurations in terms of convergence speed, signal to interference plus noise ratio (SINR) at the output of the system, adaptation process of the adaptive complex (amplitudes and phases) weights and the shaping required for array pattern with desired nulls have been studied. In all simulation, we have considered 12,40 and 80 elements linear array with interelement spacing set to 0.5λ an optimum value to avoid grating lobes. Also, it is assumed that there is one desired signal arriving from direction 0°, and two interfering signals from directions −45° and 25°, respectively, and number of iterations is 100 , $w_i(0)$ is the zero vector. The step size value of the adaptive algorithm is chosen to be $\mu = 0.006$ which ensures that the LMS algorithm converges and performs well. The results are arranged into three subsection.

3.6.1 Adaptive Array With 12 Elements

In this subsection, the number of the elements are 12, the following subsections show the results in term Updating Weights, LMS Errors, SINR and array pattern.

3.6.1.1 Analysis of the Updating Weights

The LMS adaptation process starts updating the complex weights in terms of amplitudes and phases of the four configurations with respect to the iteration number as shown in Figures 3.6- 3.13. The initial values of the amplitude weights are assumed to start from zero and they are gradually adjusted according to the LMS sense until reaching their optimum final values. From these figures, it can be seen that the standard fully adaptive array has 12 adaptive elements and the LMS algorithm optimizes the amplitudes and phases of all of these elements without any exception, whereas the regular fully adaptive subarray has 6 adaptive elements which is clearly lower than that of the original fully adaptive array. In this case, we used 6 subarrays and each of them contains 2 elements. For the third configuration, the number of the adaptive elements was chosen to be 4 among a total number of 12 elements. Then, these 4 adaptive elements are divided into 2 subarrays as the final configuration. Note that due to a very small number of adaptive subarray elements (i.e., only 2) with the last configuration, the optimum values cannot be reached. It is noted from Figures that standard fully adaptive array takes high number of iterations to reach the conversing state, this is because that all the 12 array elements are adaptive.

While the regular fully adaptive subarray. It can be seen that the required number of iterations to reach the conversing state is less compared to the standard fully adaptive. The reason behind this is that the number of array elements is reduced to 6 array elements by the configuration of a regular fully adaptive subarray which in turn reveals the benefit of this configuration. Additionally, it can also be seen from Figure 3.8 that the partially adaptive elements provide more reduction in the number of iterations to get the conversing state compared to the standard fully adaptive array and regular fully adaptive. While in the partially adaptive subarray, the conversing state is not reached; this is because the number of adaptive elements is equal to the number of the interference signal.

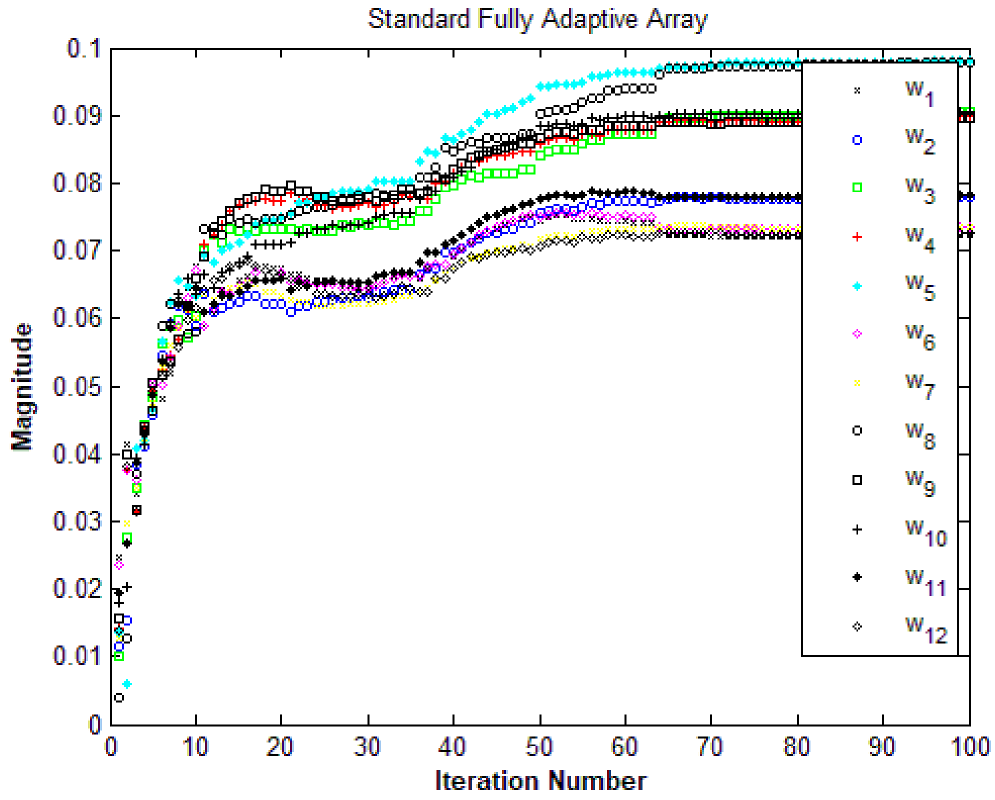


Figure 3.6. Amplitude weights of the standard fully adaptive array**.**

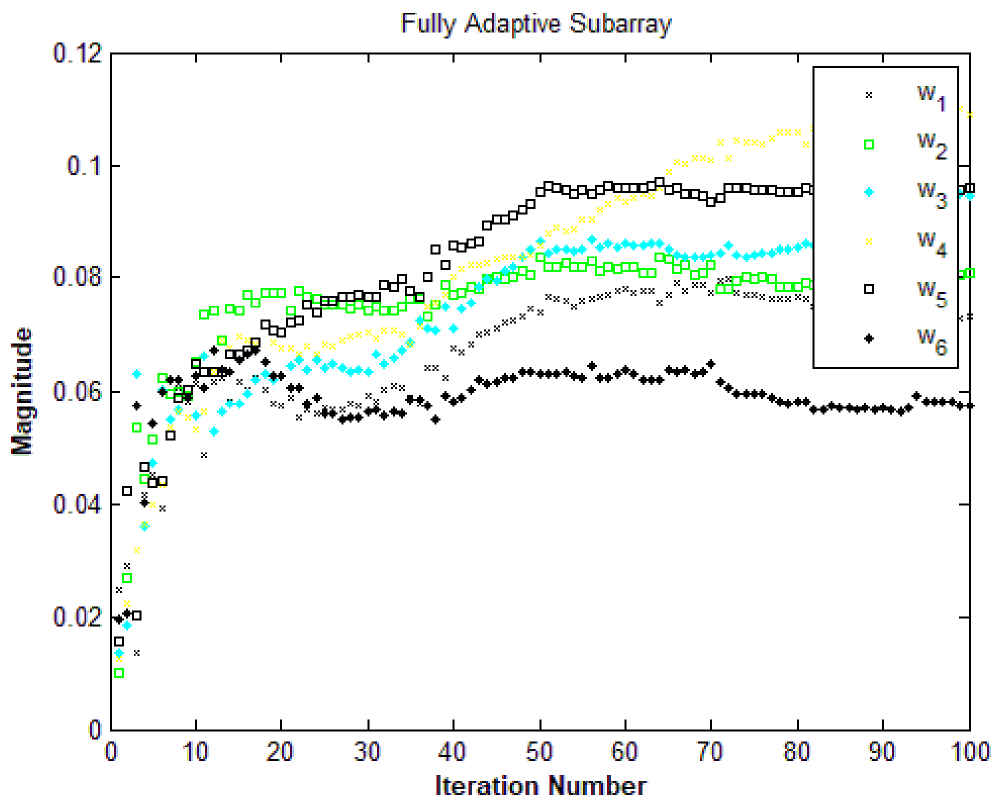


Figure 3.7. Amplitude weights of the fully adaptive subarray.

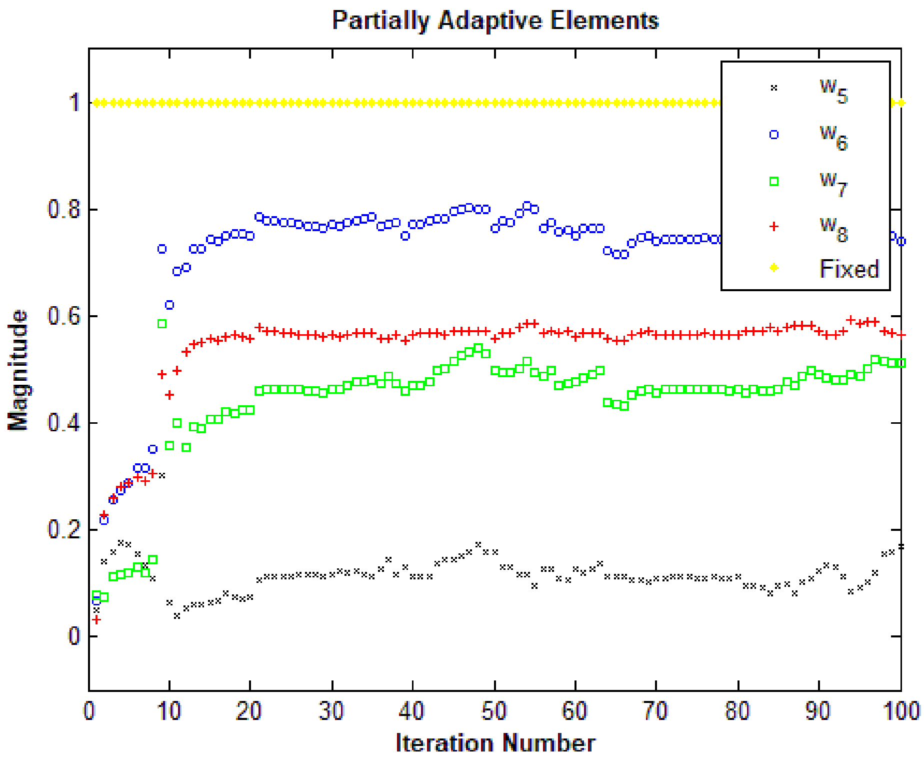


Figure 3.8. Amplitude weights of the partially adaptive elements**.**

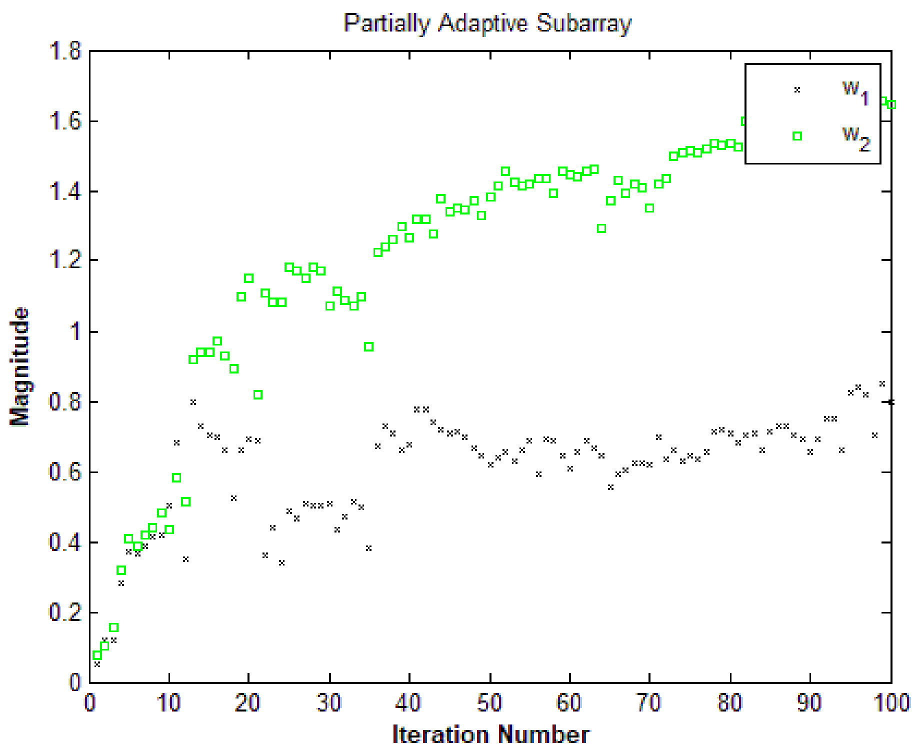


Figure 3.9. Amplitude weights of the partially adaptive subarray**.**

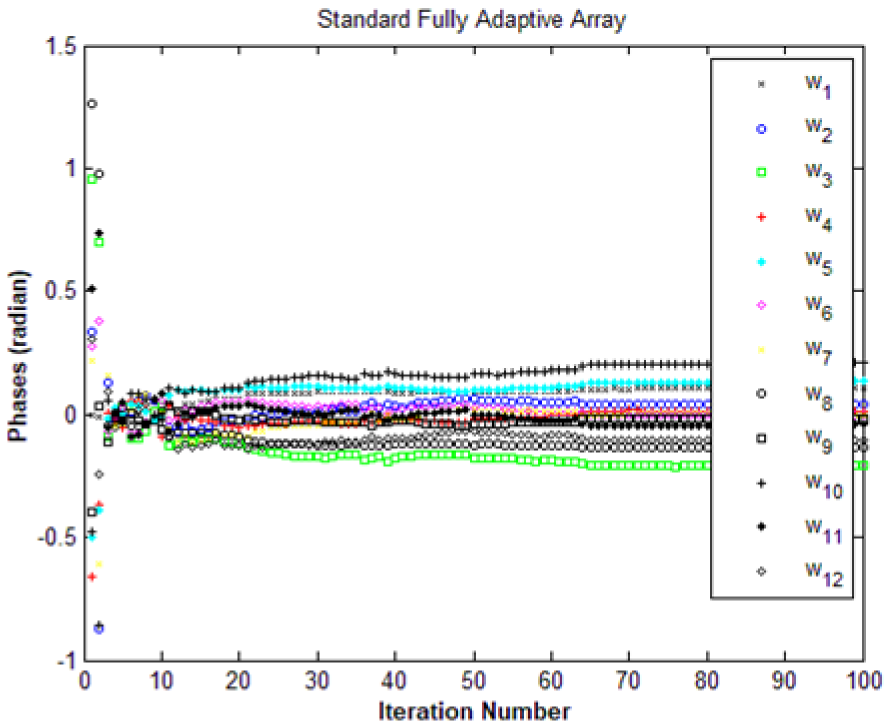


Figure.3.10. Phase weights of the standard fully adaptive array.

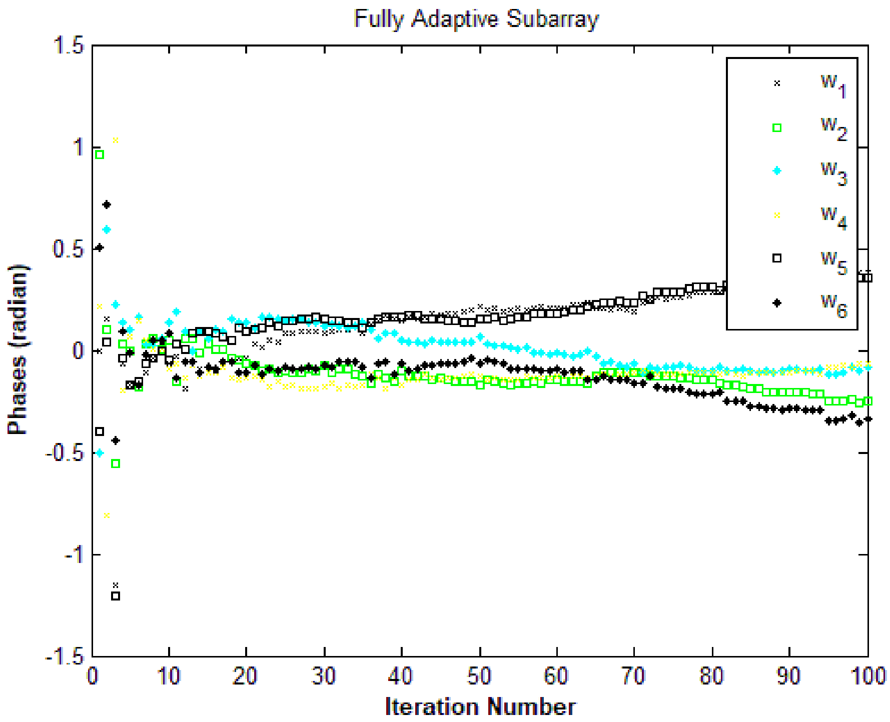


Figure.3.11. Phase weights of the fully adaptive subarray.

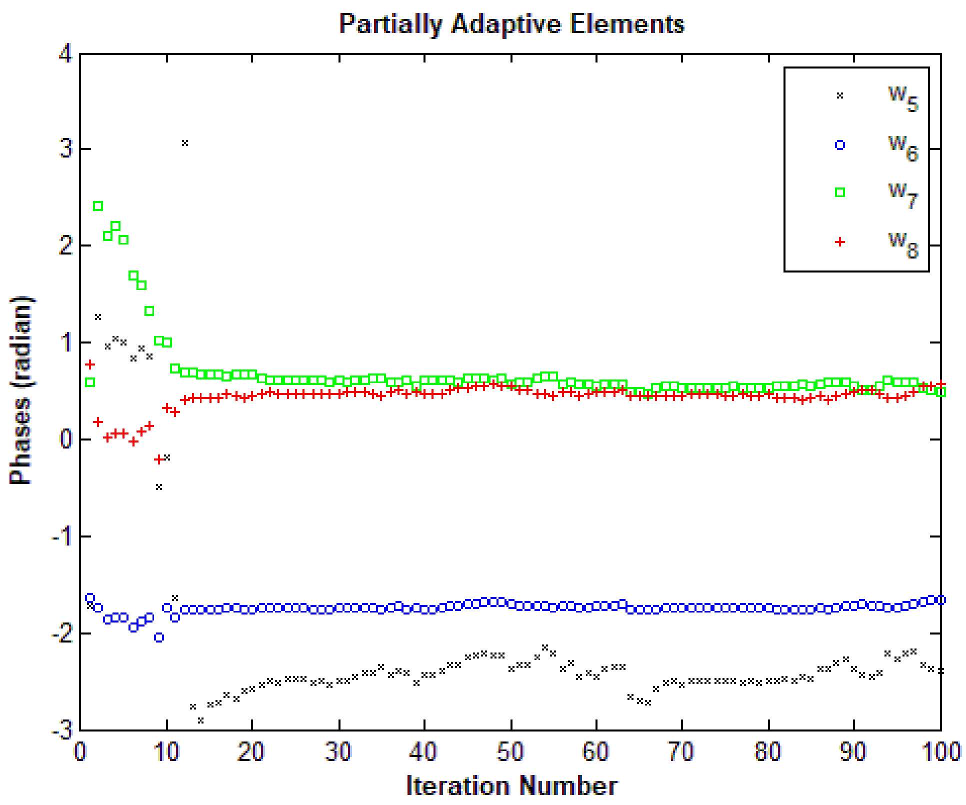


Figure.3.12. Phase weights of the partially adaptive elements**.**

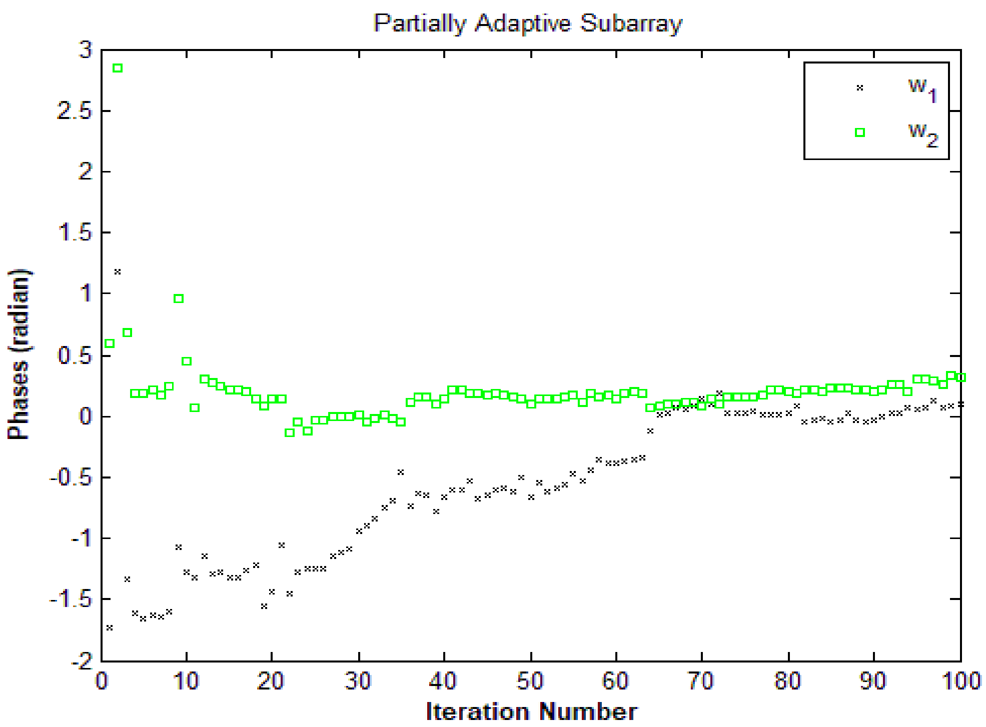


Figure.3.13. Phase weights of the partially adaptive subarray**.**

3.6.1.2 Analysis of the LMS Errors

In this subsection, the mean square error (MSE) of the output signal for the three proposed configurations with standard fully adaptive array is plotted versus the iteration number as shown in Figure.3.14. It is found that the partially adaptive elements configuration has the fastest convergence among all other configurations. This is mainly due to the fact that the number of its adaptive elements is reduced from 12 to only 4 adaptive elements which is quite enough to control the required two nulls and reduces the feeder complexity.

On the other hand, the LMS error of the partially adaptive irregular subarray is relatively larger than that of other three configurations. This is mainly because of having only 2 adaptive subarrays which are not enough for dealing with scenario of two interfering signals. Nevertheless, good convergence and lower LMS error can be obtained with the last configuration if the number of adaptive subarrays is larger than the total number of the interfering signals. Also, it is found that the convergence speed of the standard fully adaptive array is relatively slow with compared to second and third configurations.

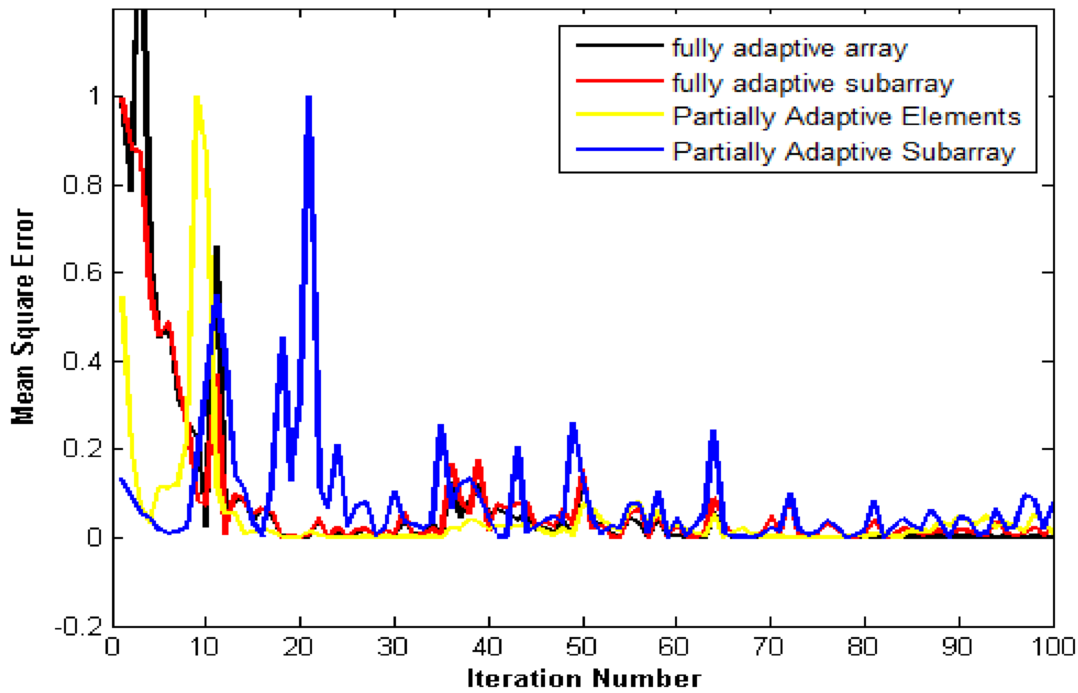


Figure.3.14. Convergence speeds of different array configurations for two interferer signals with 12 elements.

3.6.1.3 Analysis of the SINR

To illustrate the capability of the proposed configurations for interference cancellations, the signal to interference plus noise ratio at the output of those four configurations with respect to the SINR at the input is plotted as shown in Figure. 3.15. The SINR at the output of any considered configuration is computed according to the following equations

$$SINR_{\text{output}} = \frac{\bar{w}^H \overline{R_{ss}}\, \bar{w}}{\bar{w}^H \overline{R_{uu}}\, \bar{w}} \quad [3.21]$$

Whereas $\overline{R_{ss}}$ =E[$\bar{s}\bar{s}^H$] $\bar{R}_u = E[\bar{u}^H]$, and $\overline{R_{nn}} = E[\bar{n}\,\bar{n}^H]$ [3.22]

are the correlation matrices for the desired signal, interferers, and noise respectively.

From this figure, it can be observed that the output of SINR of the standard fully adaptive array configuration much better than all other configurations. Clearly, this is due to the availability of all array elements as adaptive for interference cancellation by placing deep nulls toward interfering signals. Although there are fewer number of adaptive elements with the other proposed configurations, they are still able to provide acceptable SINR at their outputs which fully confirm the effectiveness of the proposed configurations.

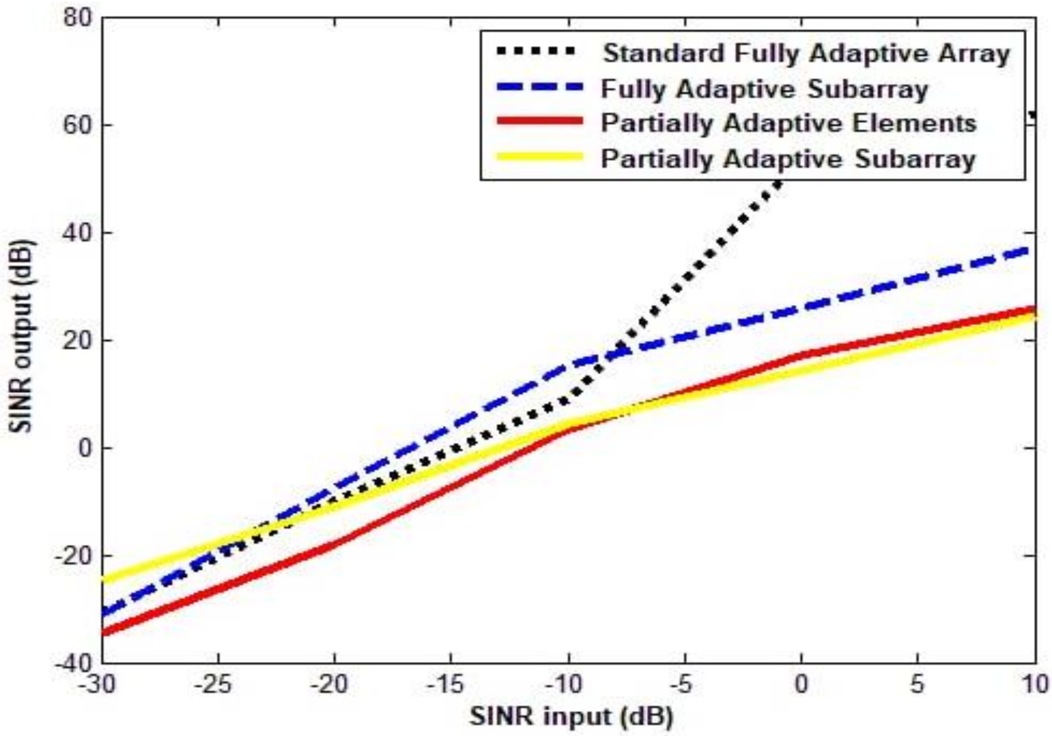


Figure.3.15: Variations of the output SINR versus input SINR with 12 elements.

3.6.1.4 Analysis of the Array Patterns

In order to see clearly the placed nulls toward the interfering directions and verify the proposed ideas, the array patterns of the above mentioned four configurations and comparisons are depicted in Figures. 3.16, 3.20. For comparison purpose, the beam pattern of the uniformly excited linear array is also included. It is found that all the array configurations have the ability to place deep and accurate nulls at the interfering directions without any distortions in the array patterns. Also, it has been noted that they are able to steer the main beam toward desired signal direction. More important, the first three configurations (i.e., standard fully adaptive array, regular fully adaptive subarray, and the partially adaptive elements) which they have 12, 6, and 4 adaptive elements respectively have better ability to place deep nulls than that of the last configuration which has only two adaptive subarrays

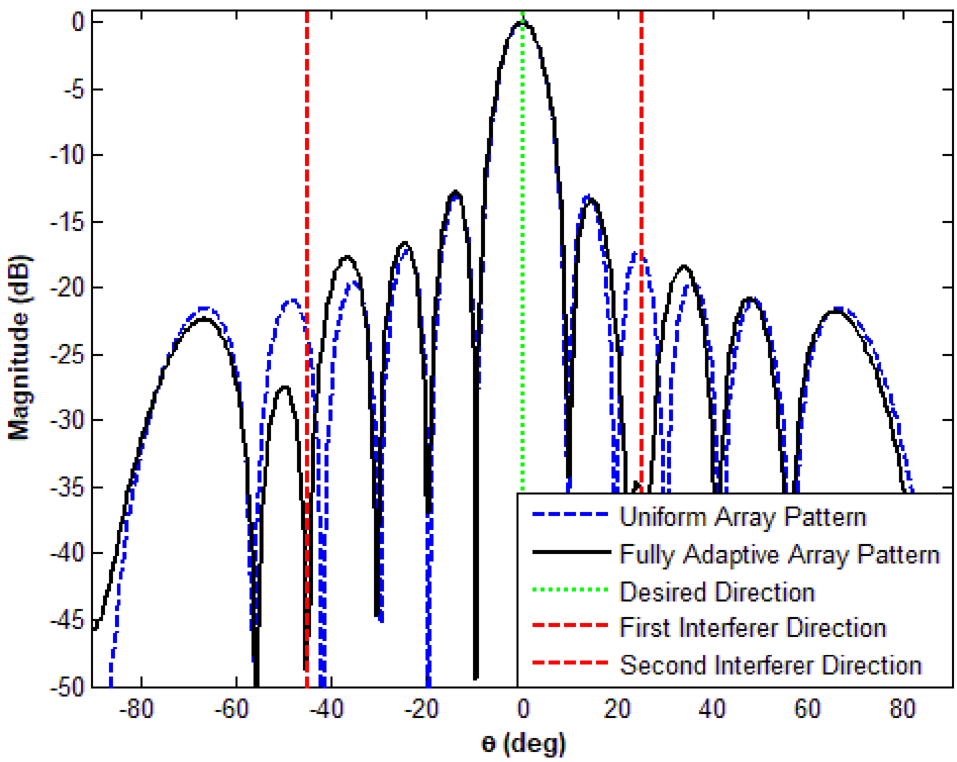


Figure.3.16. Array patterns of the fully adaptive array.

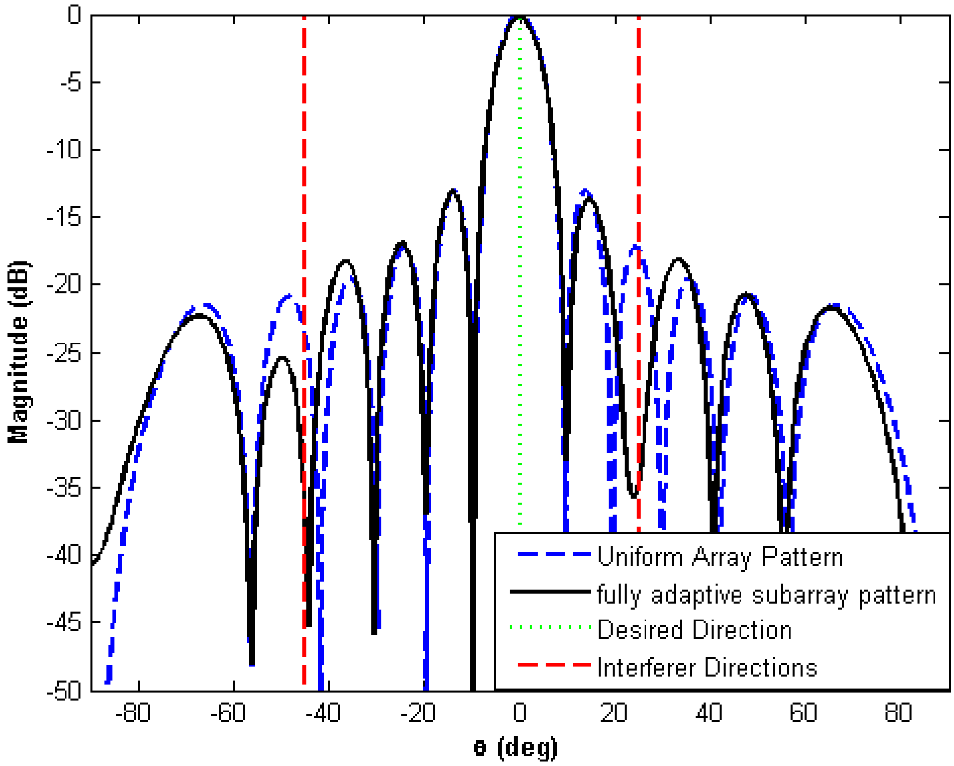


Figure.3.17. Array patterns of the fully adaptive subarray.

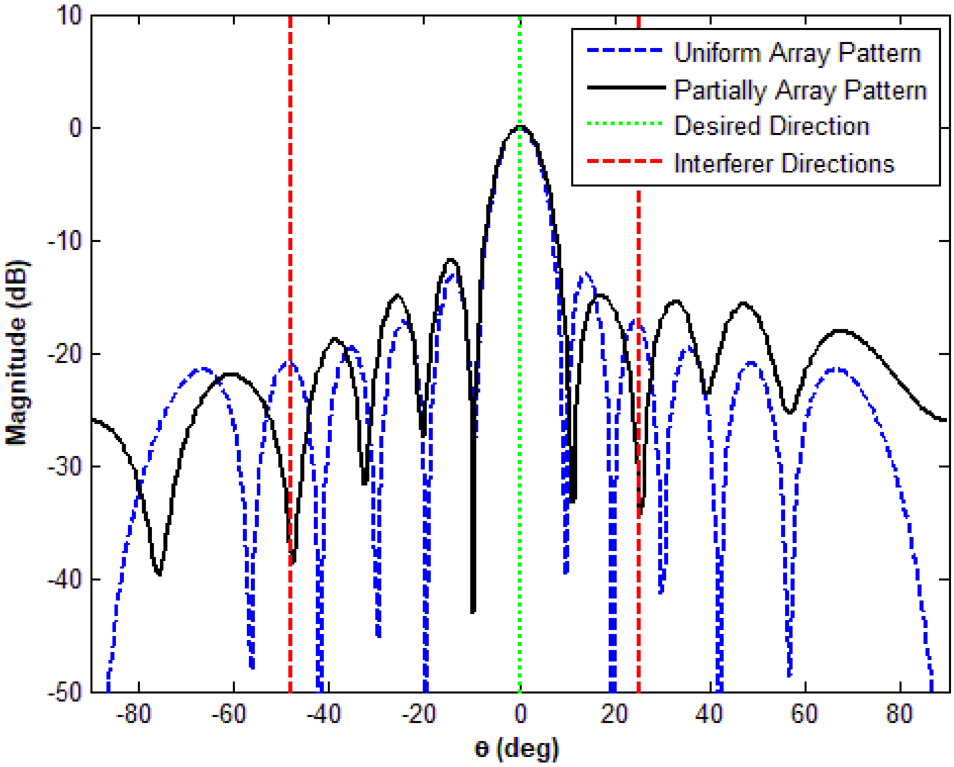


Figure.3.18. Array patterns of the partially adaptive element.

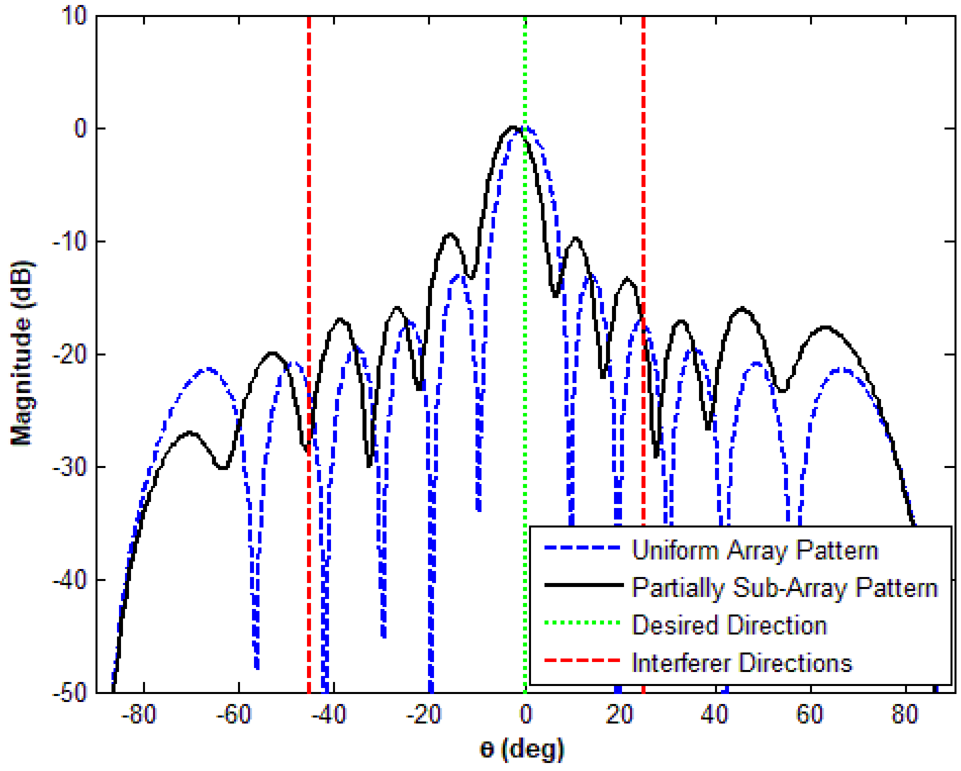


Figure.3.19. Array patterns of partially adaptive subarray.

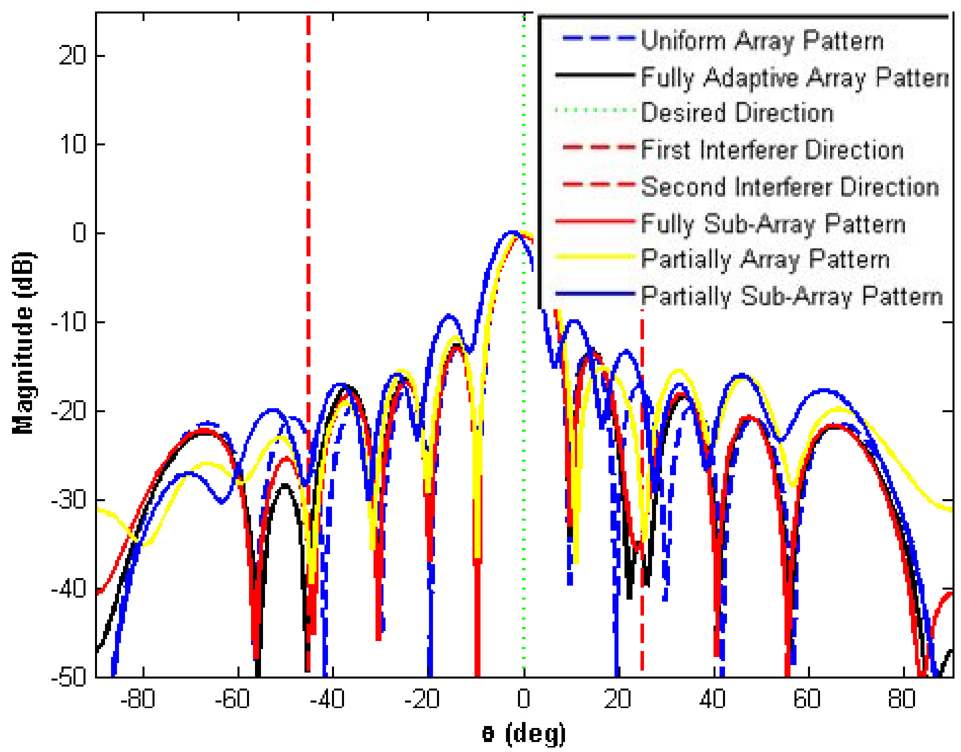


Figure.3.20. Array patterns of different array configurations for two interferer signals with 12 elements.

3.6.2.Adaptive Array with 40 Elements

In this section the number of the elements are 40, the following subsections show the results in term updating weights, LMS errors, SINR and array pattern.

3.6.2.1 Analysis of the Updating Weights

As seen in Figures 3.21-3.28, the LMS adaptation process begins updating the complex weights in terms of amplitudes and phases of the aforementioned four configurations with regard to the iteration number. Assuming that the starting values of the amplitude weights begin at zero, they are gradually changed in accordance with the LMS sense until they reach their optimal end values. The standard fully adaptive array has 40 adaptive elements, and the LMS algorithm optimizes the amplitudes and phases of each of these elements without exception. In contrast, the regular fully adaptive subarray has only 10 adaptive elements, which is significantly less than the original fully adaptive array. In this instance, we utilized 10 subarrays, each containing 4 elements. The number of adaptive elements in the third configuration was set at 10 out of a total of 40 elements. Then, these 10 adaptive elements are divided into 5 subarrays as the final configuration.

The subsequent results show that the standard fully adaptive array takes a lot of iterations to reach the converging state. This is because all 40 array elements are adaptive. Subsequently, the fully adaptive subarray performs better when it is compared to the standard fully adaptive array, since the number of iterations needed to reach the converging state is less. The reason for this is that a regular fully adaptive subarray reduces the number of adaptive array elements to 10 adaptive elements .

From the results, it is also observed that the partially adaptive elements reduce the number of iterations needed compared to the standard fully adaptive array and regular fully adaptive elements. Finally, the partially adaptive subarray reach converging state with less number of iterations compared to all other configurations. This is because the number of adaptive elements is reduced to 5 adaptive elements which in turn reveals the advantage of this configuration.

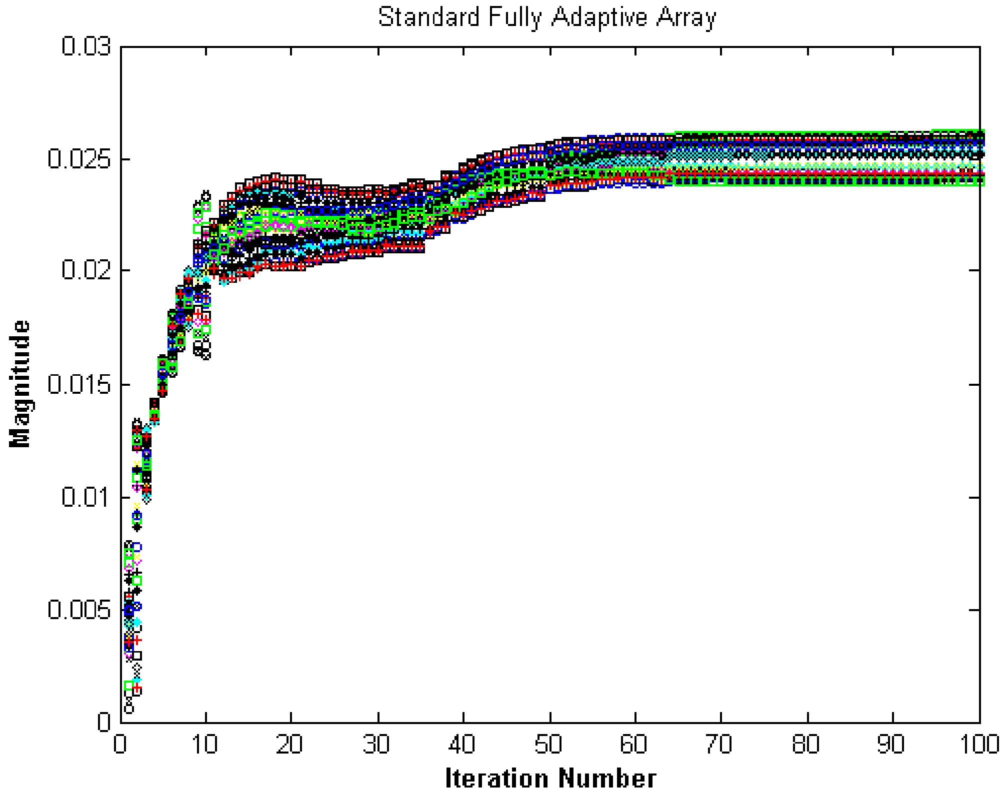


Figure.3.21. Amplitude weights of the standard fully adaptive array.

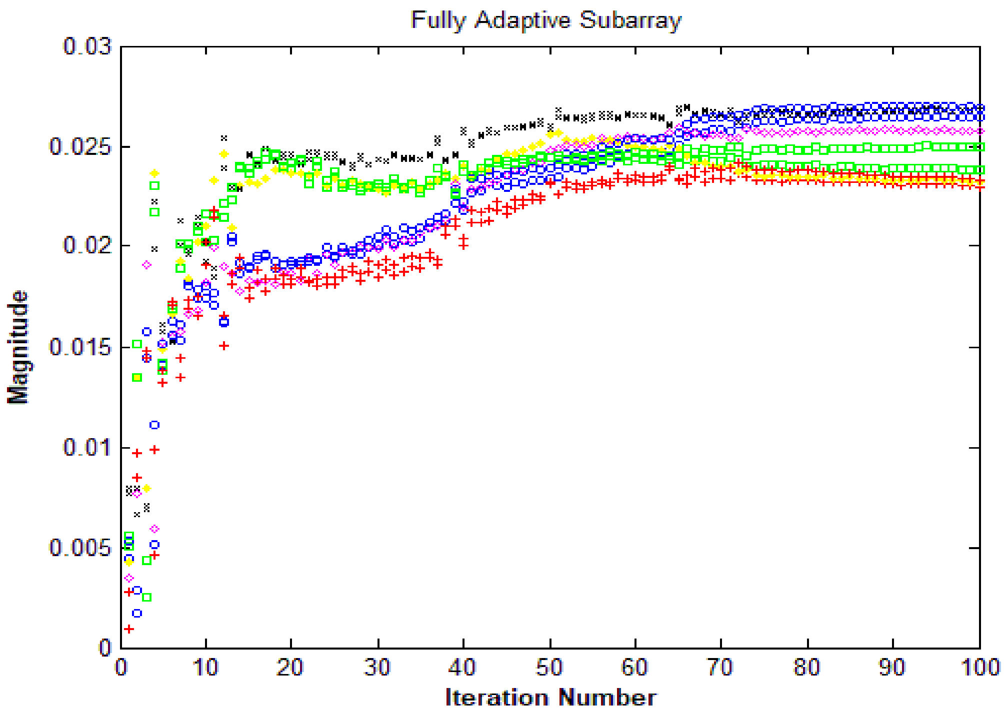


Figure.3.22. Amplitude weights of the fully adaptive subarray.

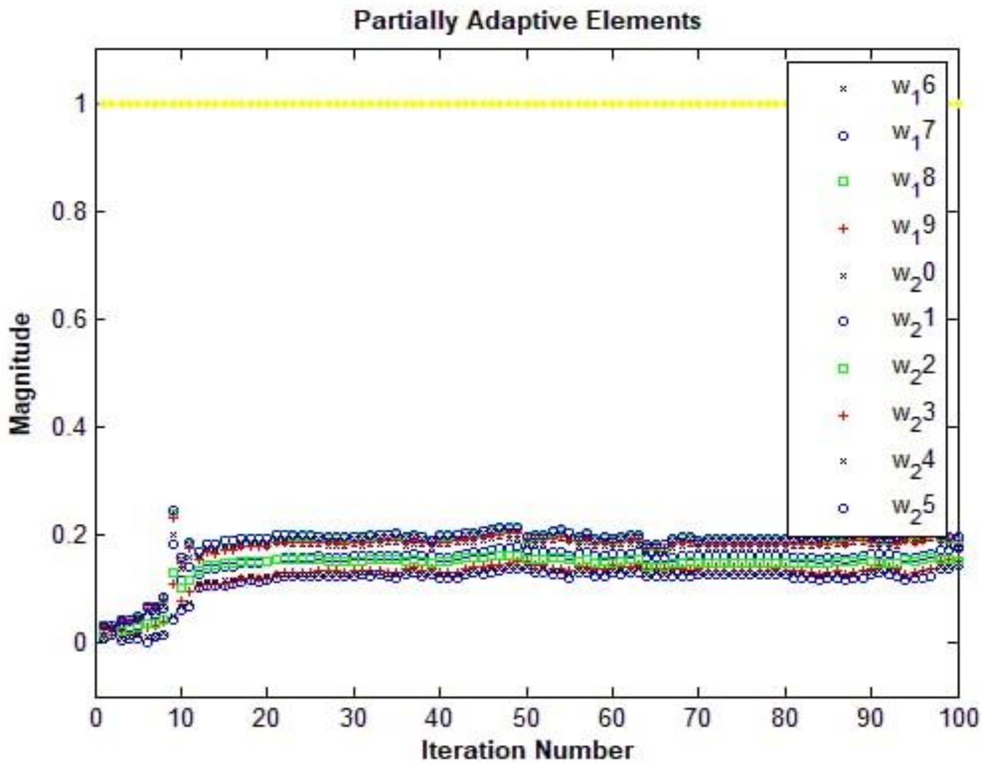


Figure.3.23. Amplitude weights of the partially adaptive elements.

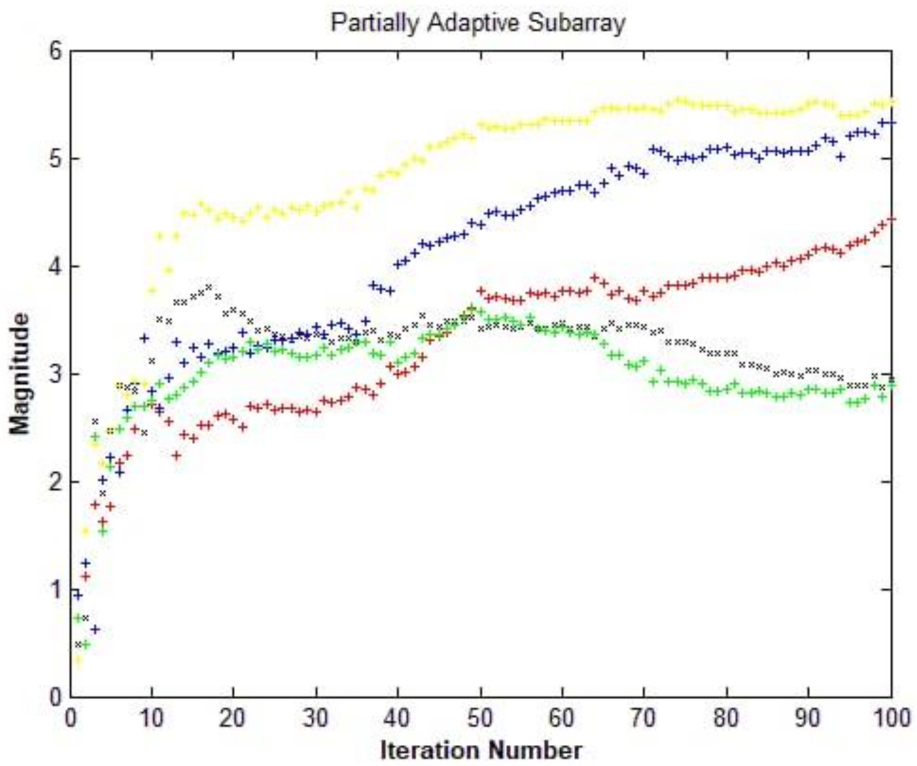


Figure.3.24. Amplitude weights of the partially adaptive subarray.

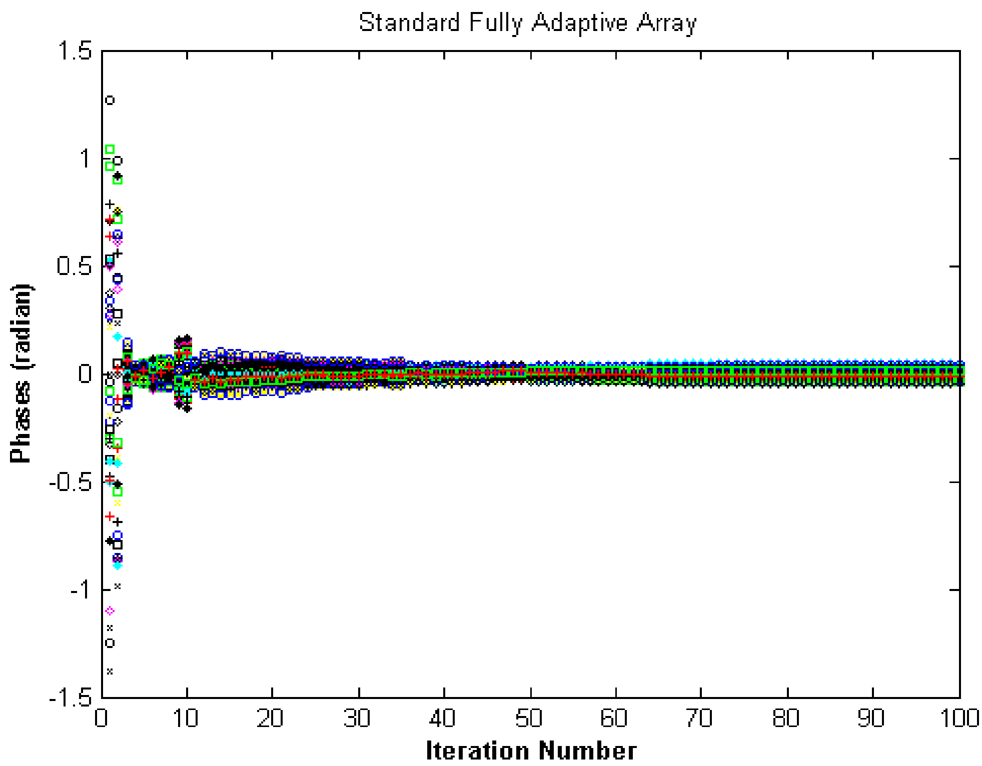


Figure.3.25. Phase weights of the standard fully adaptive array.

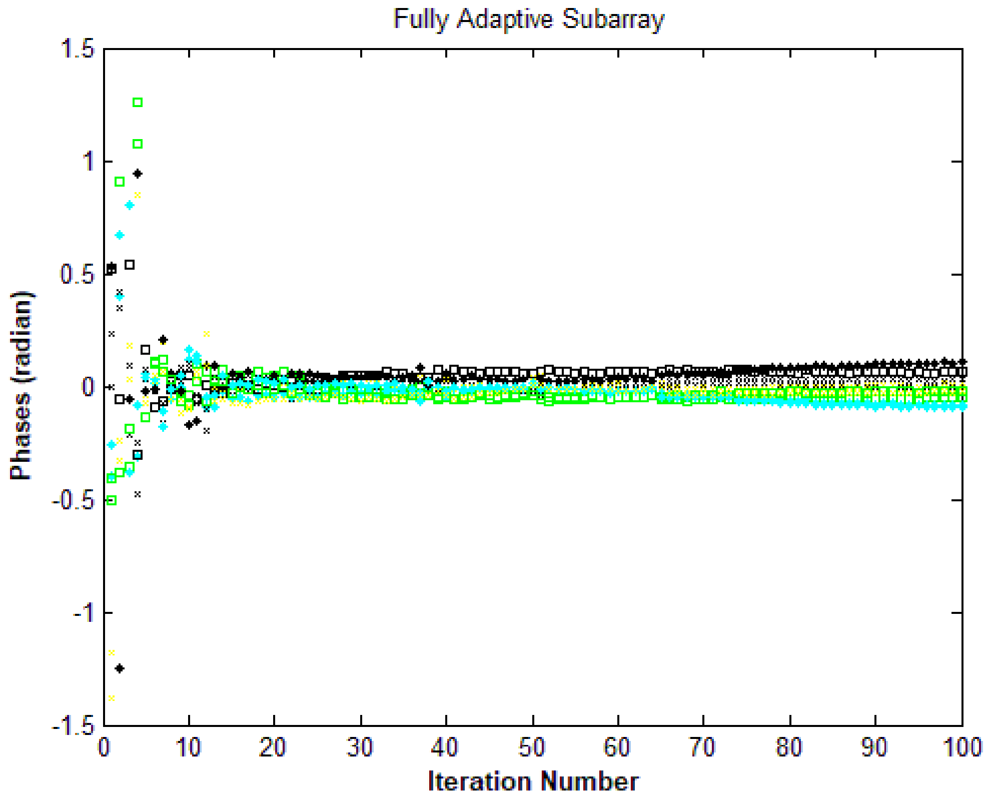


Figure.3.26. Phase weights of the fully adaptive subarray.

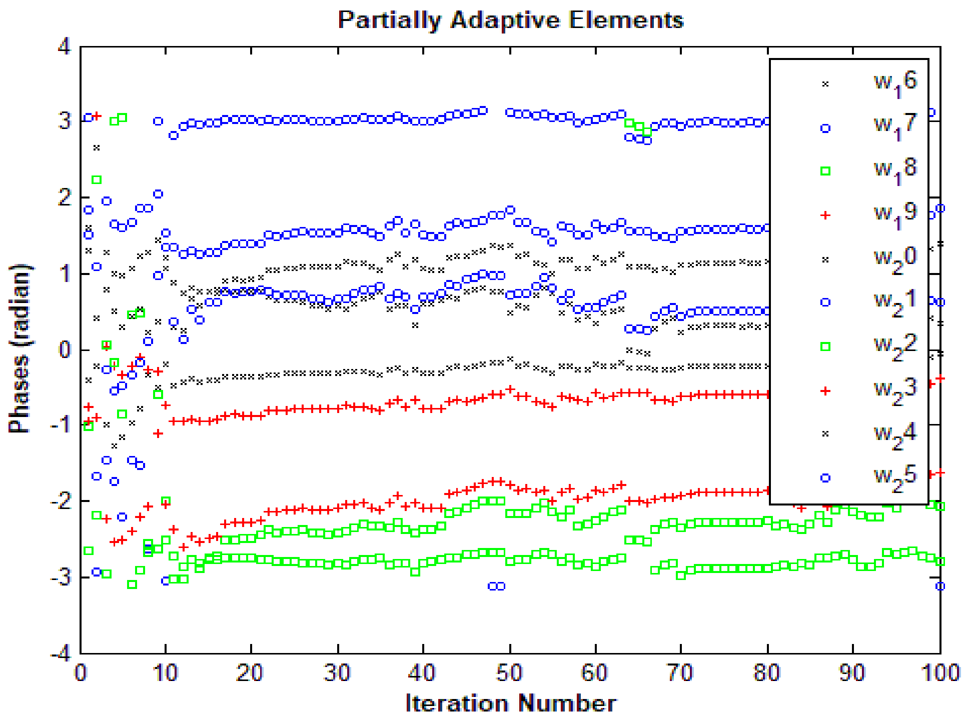


Figure.3.27. Phase weights of the partially adaptive elements.

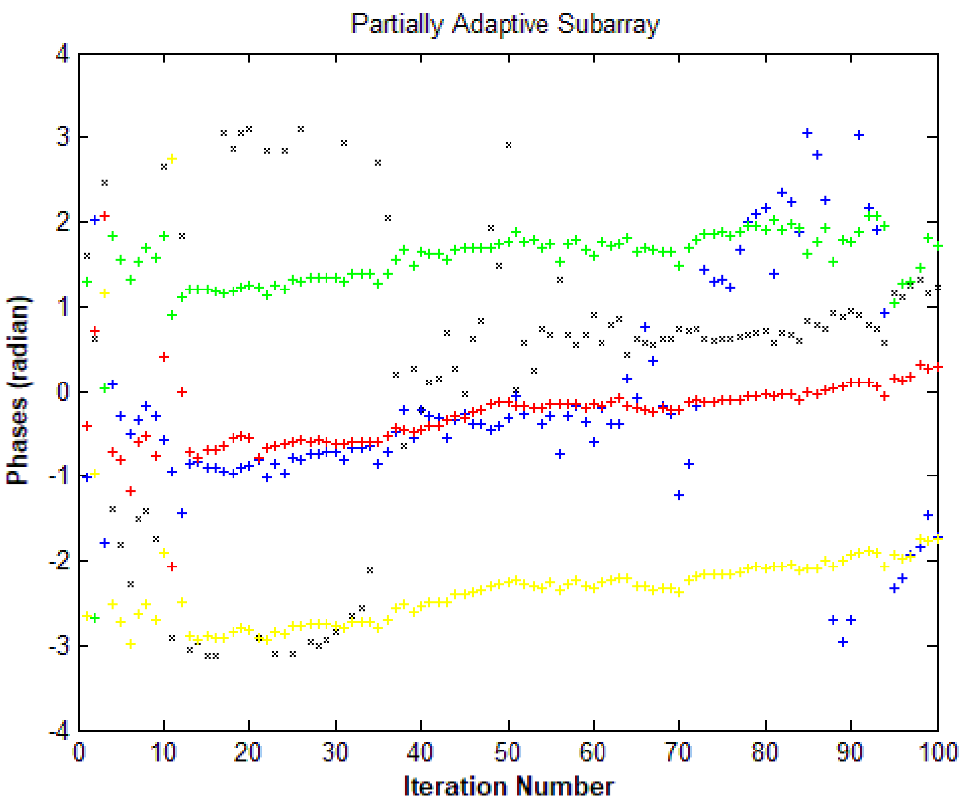


Figure.3.28. Phase weights of the partially adaptive subarray.

3.6.2.2 Analysis of the LMS Errors

Figure 3.29 depicts the mean square error (MSE) of the output signal for the thee proposed configurations with standard fully adptive array versus the number of iterations. In comparison to all other configurations, the partially subarray adaptive elements configuration has the fastest convergence. This is mostly because the number of its adaptive elements has been decreased from 40 to 5, which is sufficient to control the required two nulls and decreases the complexity of the feeder. Also, compared to the second and third configurations, the convergence speed of the standard fully adaptive array is quite slow. Additionally, system noise increases as the number of antenna array elements increases and total MSE tends to be almost the same for the specified antenna element values.

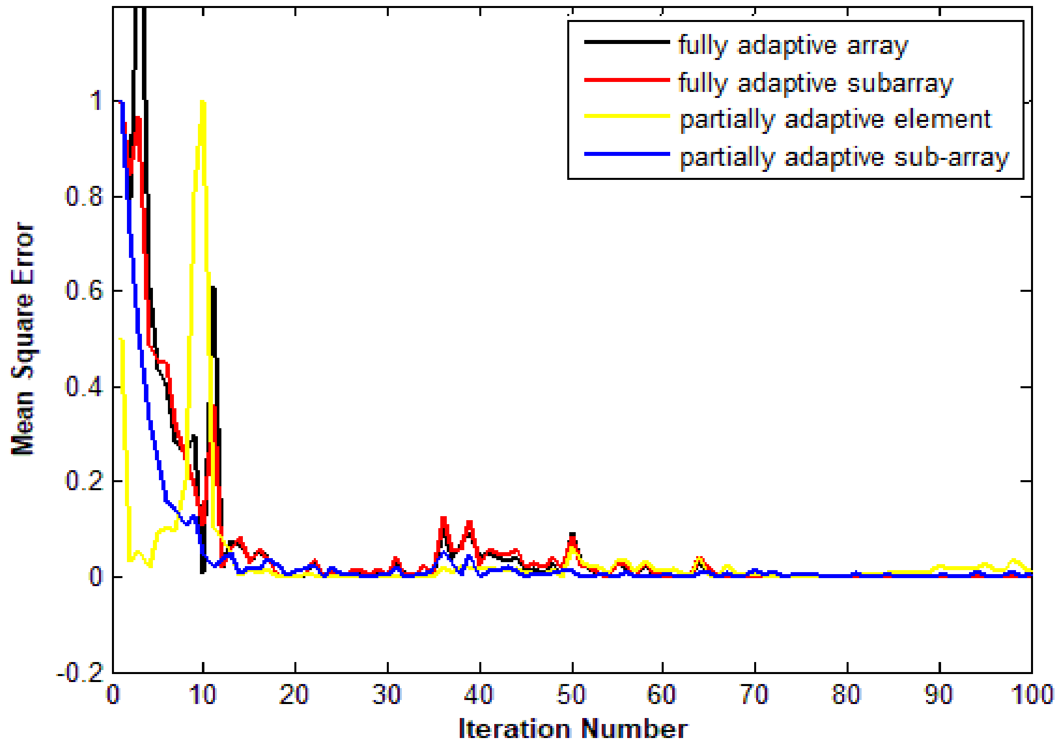


Figure.3.29. Convergence speeds of different array configurations for two interferer signals with 40 elements.

3.6.2.3. Analysis of the SINR

The signal-to-interference-plus-noise ratio at the output of these four configurations and their comparisons relative to the SINR at the input is presented in Figure 3.30 to highlight the interference cancelling capacity of the suggested configurations. The equations (3.21) and (3.22) are used to calculate the SINR at the output of any configuration that is taken into consideration. are the correlation matrices for the desired signal, interferers, noise respectively. It can be seen from this figure that the output SINR of the standard fully adaptive array configuration is significantly better than that of any other configurations. Clearly, this is because all array elements are adaptive for interference cancellation by providing deep nulls in the direction of interfering signals. Although the other proposed configurations have less adaptive elements, they are still able to produce adequate SINR at their outputs, confirming the usefulness of the proposed configurations.

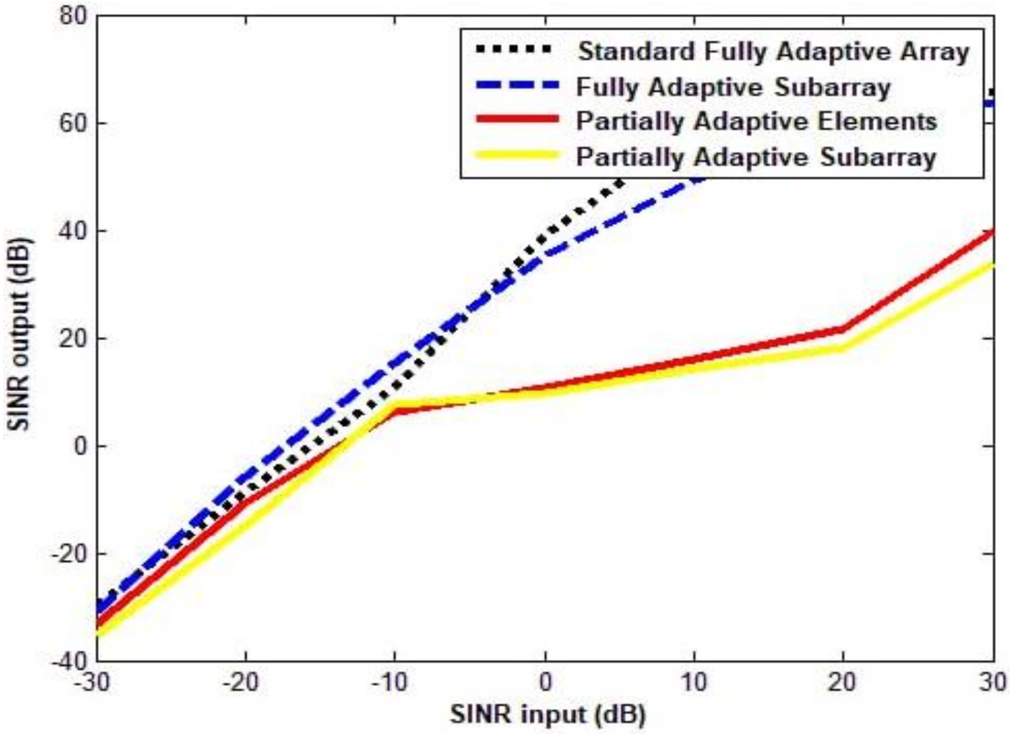


Figure.3.30. Variations of the output SINR versus input SINR with 40 elements**.**

3.6.2.4 Analysis of the Array Patterns

Simulation results indicate that when the number of antenna array elements increases from 12 to 40, the beam width becomes narrow and the number of side lobes increases. However, the level of these side lobes is minimal in comparison to those created by a limited number of elements. All array configurations are found to be capable of placing deep and precise nulls in the interference directions without distorting the array patterns. Also it is noted that they are able to redirect the main beam in the direction of the desired signal.

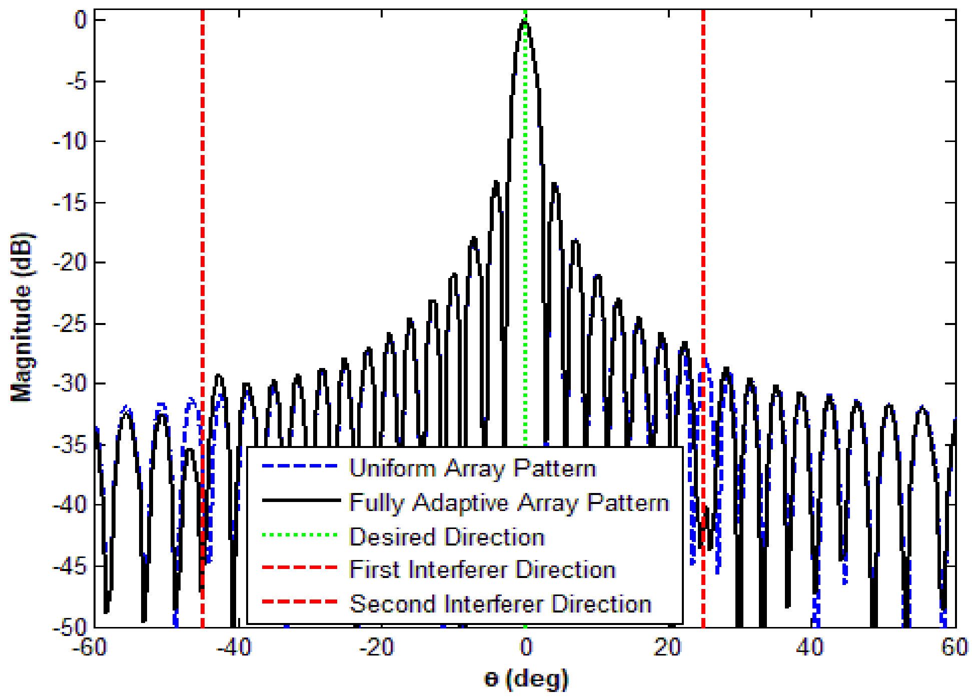


Figure.3.31. Array patterns of the fully adaptive array.

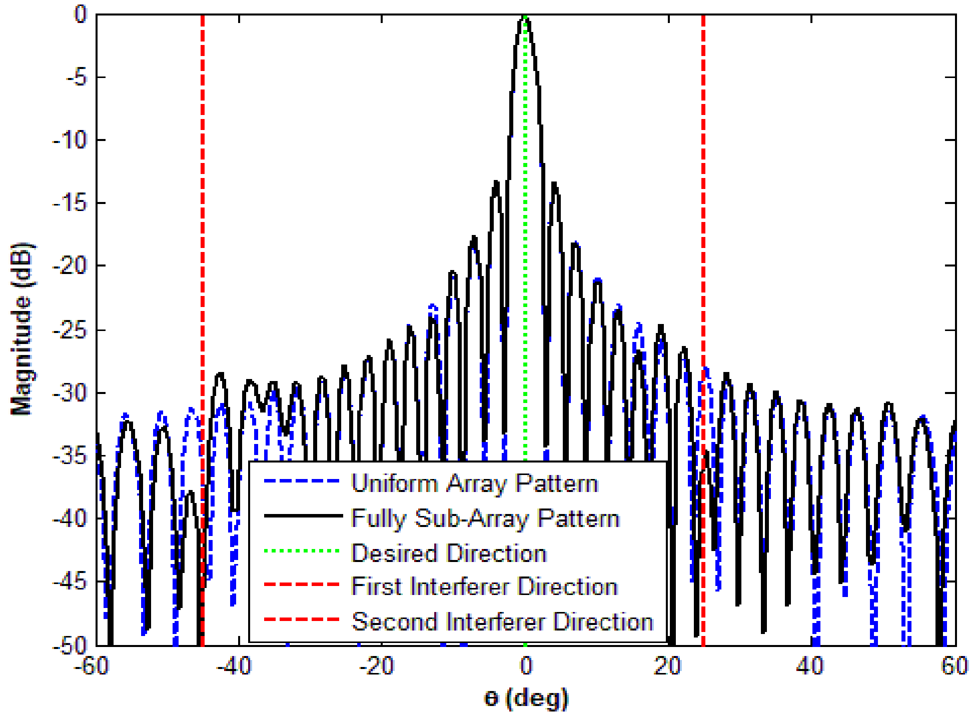


Figure.3.32. Array patterns of the fully adaptive subarray.

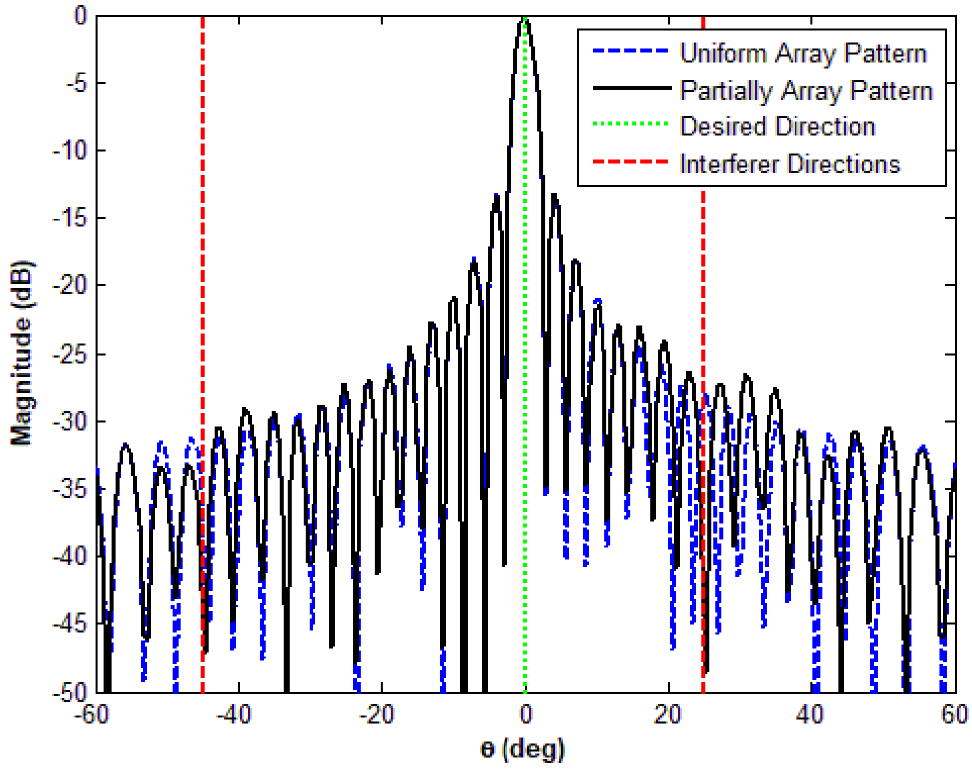


Figure.3.33. Array patterns of the partially adaptive element.

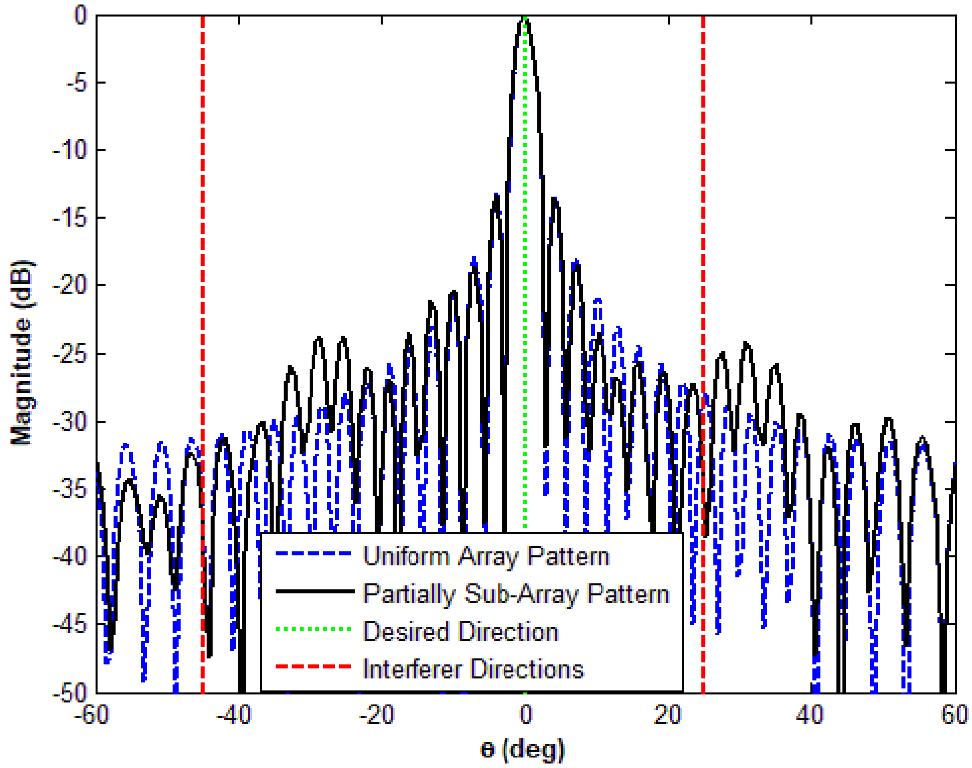


Figure.3.34. Array patterns of partially adaptive subarray.

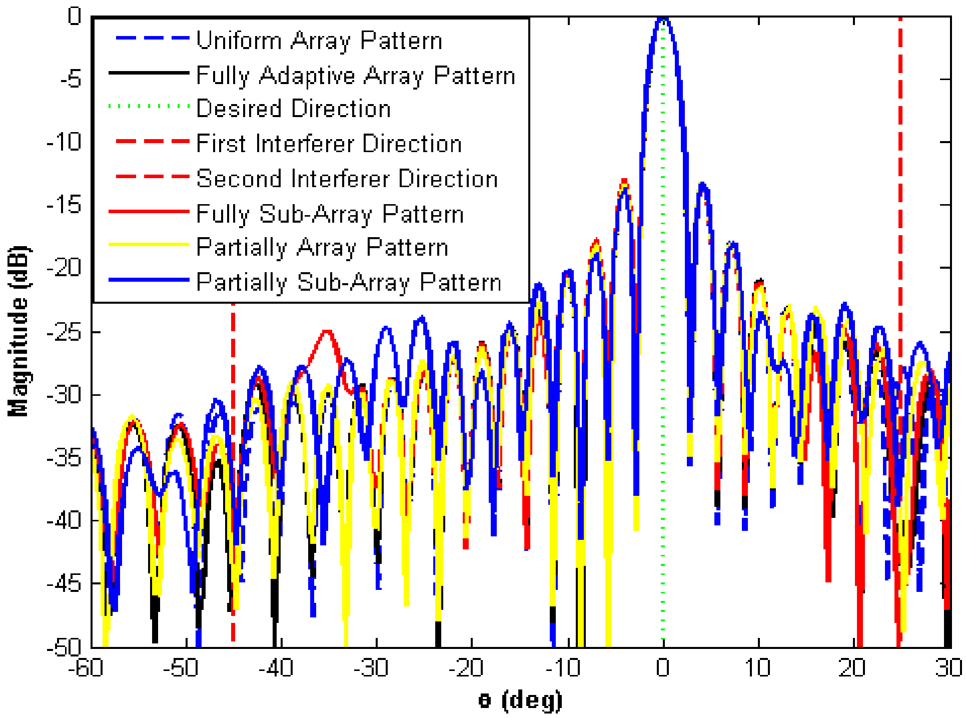


Figure.3.35 Array patterns of different array configurations for two interferer signals with 40 elements.

3.6.3 Adaptive Array with 80 elements

In this section the number of the elements are 80, the following subsections show the results in term Updating Weights, LMS Errors, SINR and array pattern.

3.6.3.1 Analysis of the Updating Weights

As illustrated in Figures 3.36 and 3.43, the LMS adaptation process begins by updating the complex weights for the amplitudes and phases of the aforementioned four configurations with regard to the iteration number. The amplitude weights are assumed to begin at zero and are then iterated according to the LMS sense until the optimal values are reached. From these figures, it can be seen that the standard fully adaptive array has 80 adaptive elements and the LMS algorithm optimizes the amplitudes and phases of all of these elements without any exception, whereas the regular fully adaptive subarray has

10 adaptive elements which is clearly lower than that of the original fully adaptive array. In this scenario 10 subarrays were employed, each of which contained 8. As for the third configuration, out of 80 elements, only 20 were selected to be the adaptive elemnts. The final configuration consists of dividing these 20 adaptive elements into 10 subarrays.

From the results of the standard fully adaptive array, it shown that standard fully adaptive array takes a lot of iterations to reach the converging state. This is because all 80 array elements are adaptive. While, the fully adaptive subarray shows less number of iterations when it is compared to the standard fully adaptive array. The reason for this is that the regular fully adaptive subarray reduces the number of adaptive array elements to 10 adaptive elements. Additionally, the partially adaptive elements reduce the number of iterations needed compared to the standard fully adaptive array and regular fully adaptive elements. Finally, it is also noted that partially adaptive subarray reach the converging state with less number of iterations compared to all other configurations. This is because the number of adaptive elements is reduced to 10 adaptive elements which in turn reveals the advantage of this configuration.

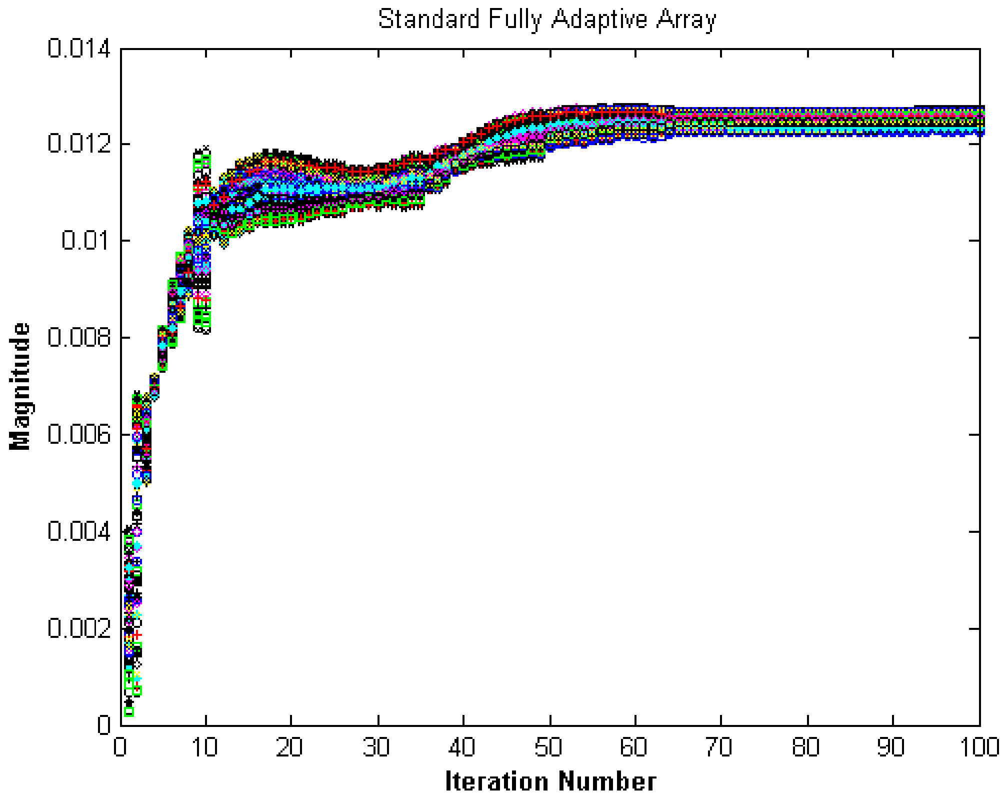


Figure.3.36. Amplitude weights of the standard fully adaptive array.

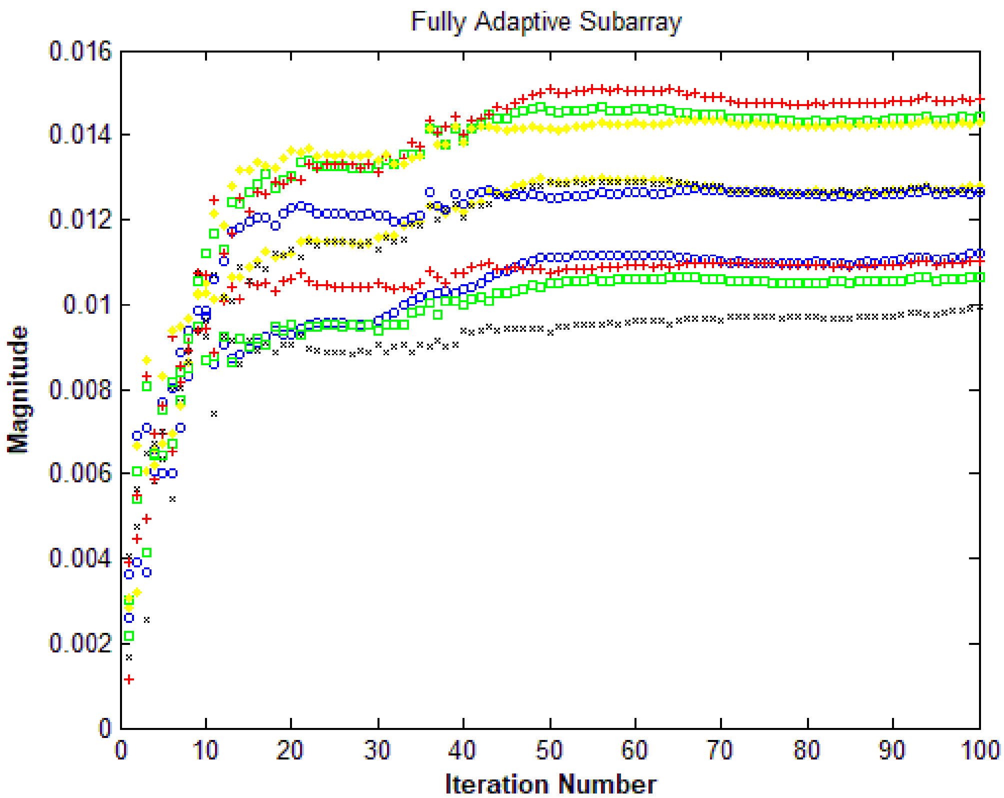


Figure.3.37. Amplitude weights of the fully adaptive subarray.

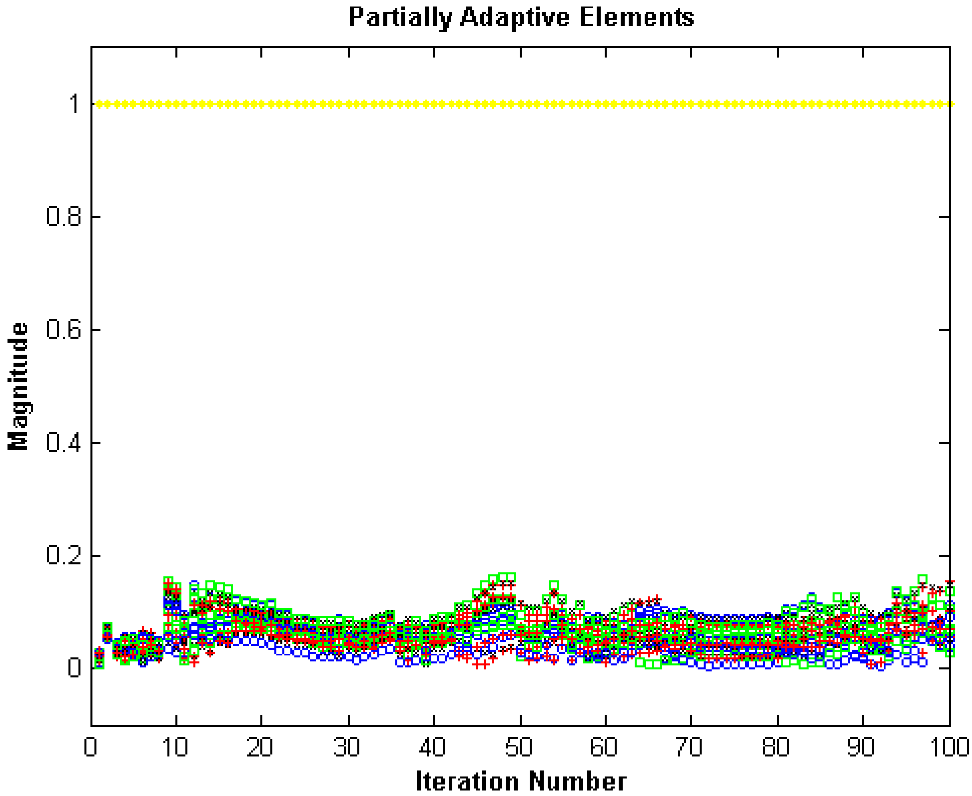


Figure.3.38. Amplitude weights of the partially adaptive elements**.**

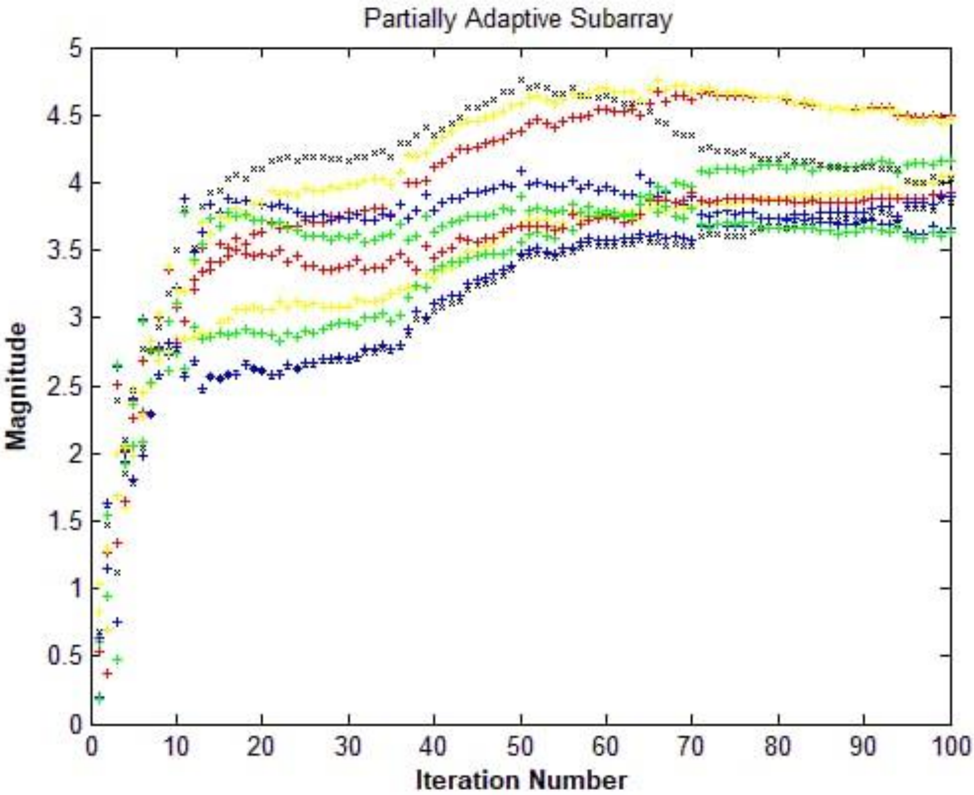


Figure.3.39. Amplitude weights of the partially adaptive subarray.

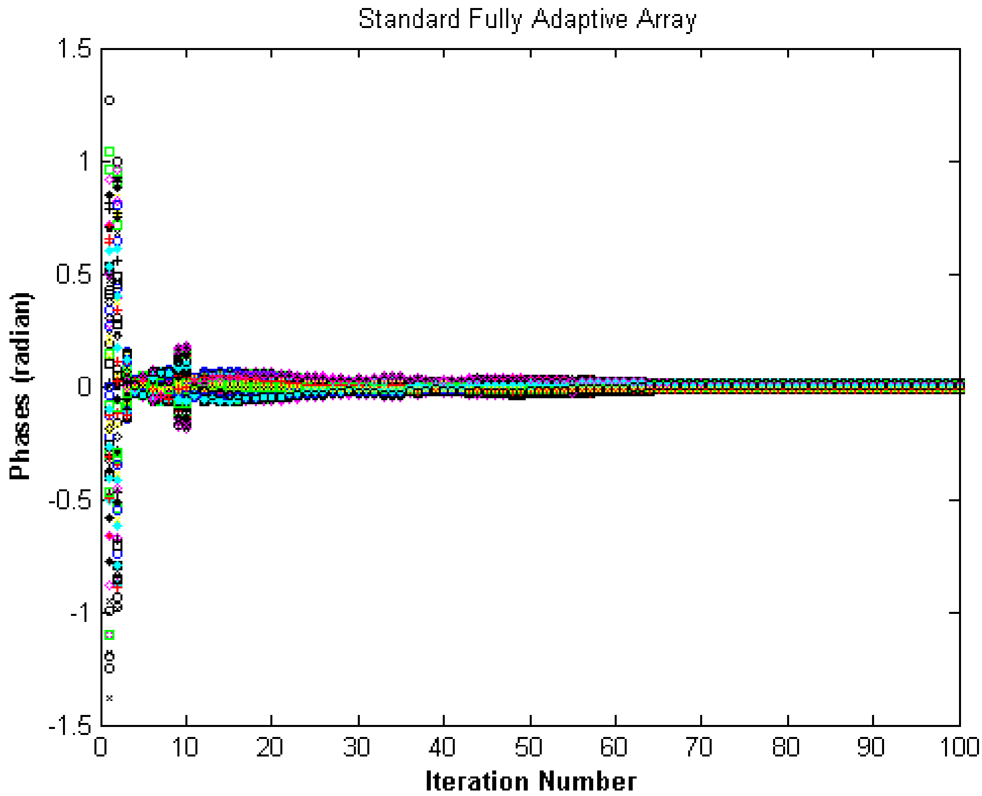


Figure.3.40. Phase weights of the standard fully adaptive array.

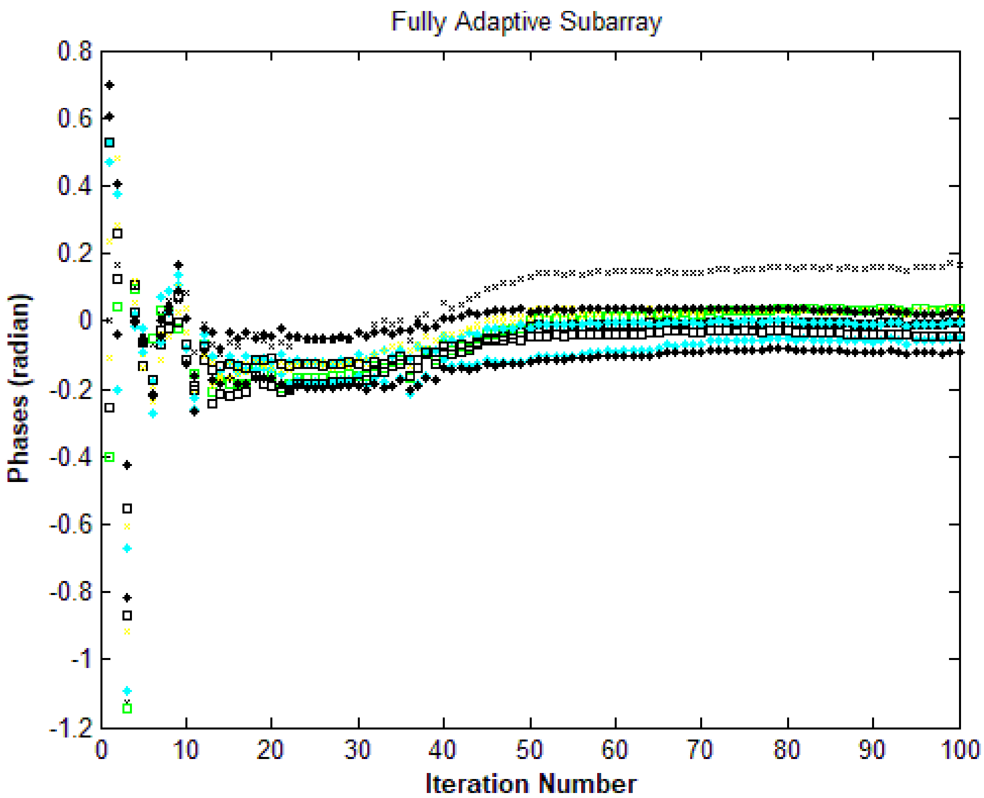


Figure.3.41. Phase weights of the fully adaptive subarray.

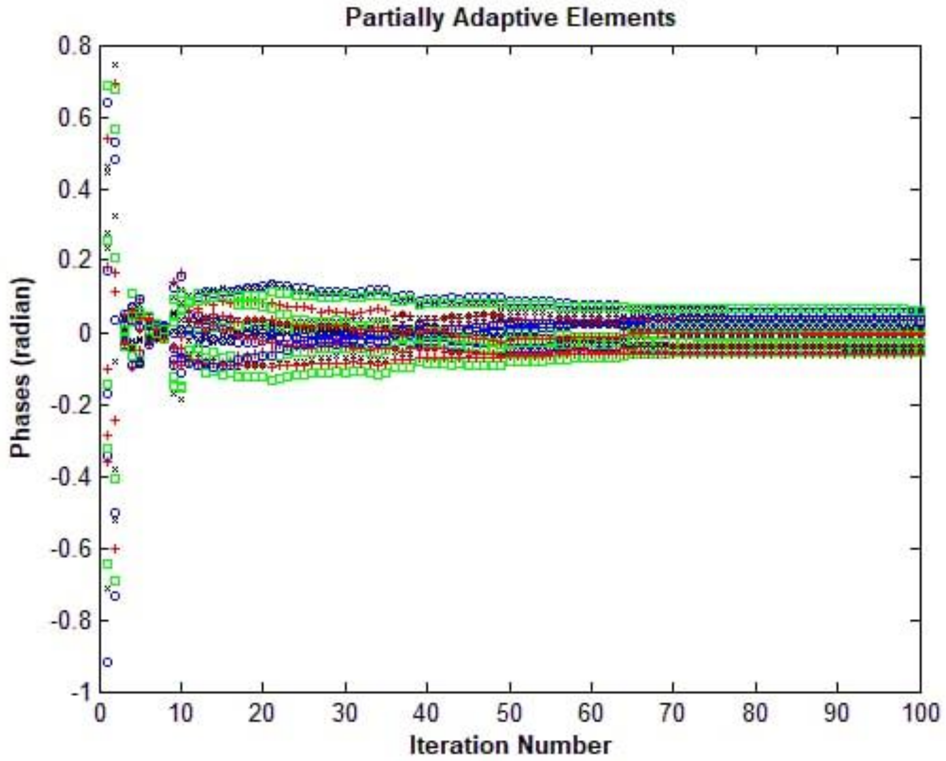


Figure.3.42. Phase weights of the partially adaptive elements**.**

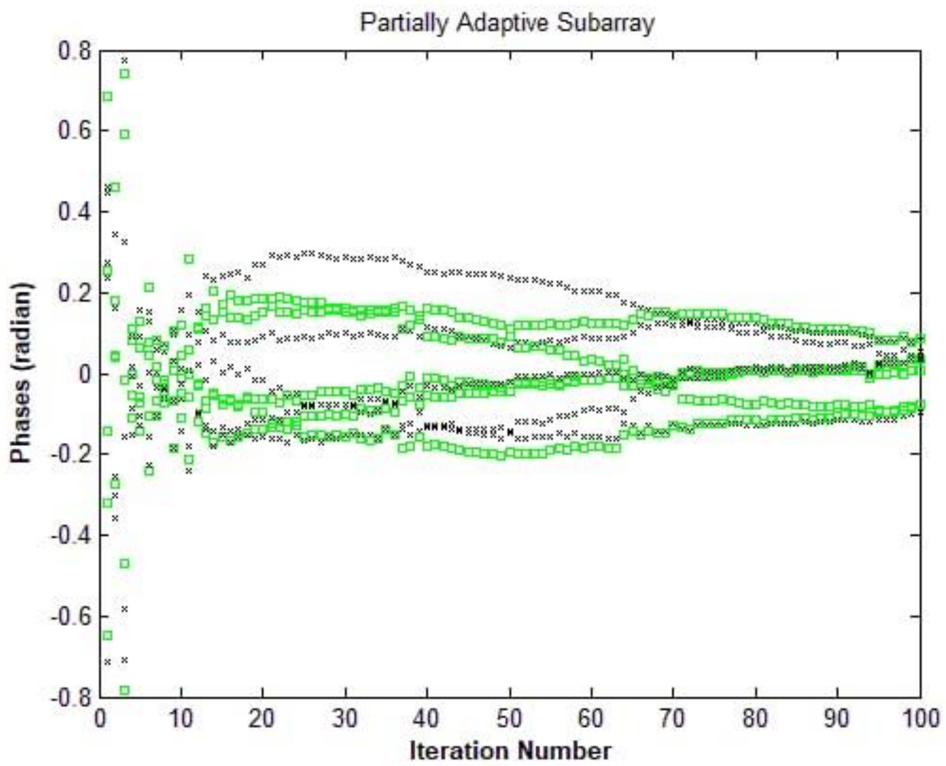


Figure.3.43. Phase weights of the partially adaptive subarray.

3.6.3.2 Analysis of the MSE

In this subsection, an illustration of the MSE of the output signal against the number of iterations for each of the four configurations and their comparisons are shown in the figure 3.44. The partially subarray adaptive elements configuration is shown to have the fastest convergence. Mainly, because of the feeder complexity is decreased from 80 to 10 adaptive elements, which is more than adequate to regulate the required two nulls. The standard fully adaptive array is also found to have a poor convergence speed compared to the second and third configurations. additionally, raising in the number of antenna array elements are accompanied by a corresponding rise in overall system noise.

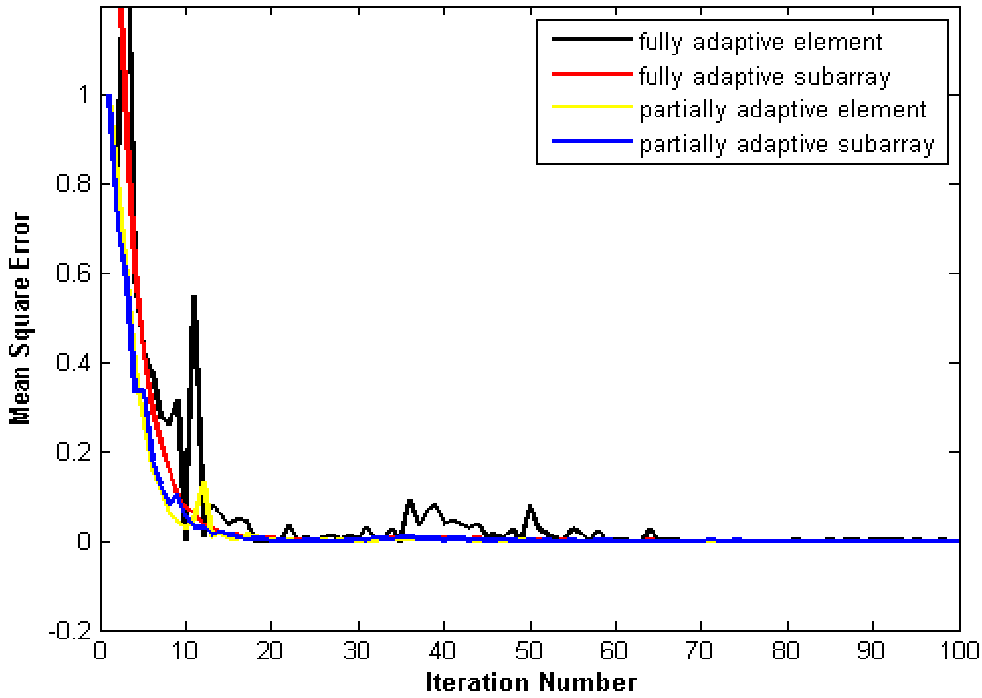


Figure.3.44. Convergence speeds of different array configurations for two interferer signals with 80 elements.

3.6.3.3 Analysis of the SINR

The signal-to-interference-plus-noise ratio at the output of these four configurations and their comparisons relative to the SINR at the input is presented in Figure. 3.45 to demonstrate the interference cancelling capabilities of the suggested configurations The signal-to-interference-plus-noise ratio (SINR) at the output of any feasible configuration are calculated using the equations (3.21) and (3.22) respectively.

It can be seen from the figure that the output SINR of the conventional fully adaptive array arrangement is significantly higher than that of any other configurations. Clearly, this is because all array elements are adaptive for interference cancellation by placing deep nulls in the direction of interfering signals. Although the other proposed configurations have a smaller number of adaptive elements, they are nevertheless able to produce adequate SINR at their outputs, confirming the usefulness of the proposed configurations.

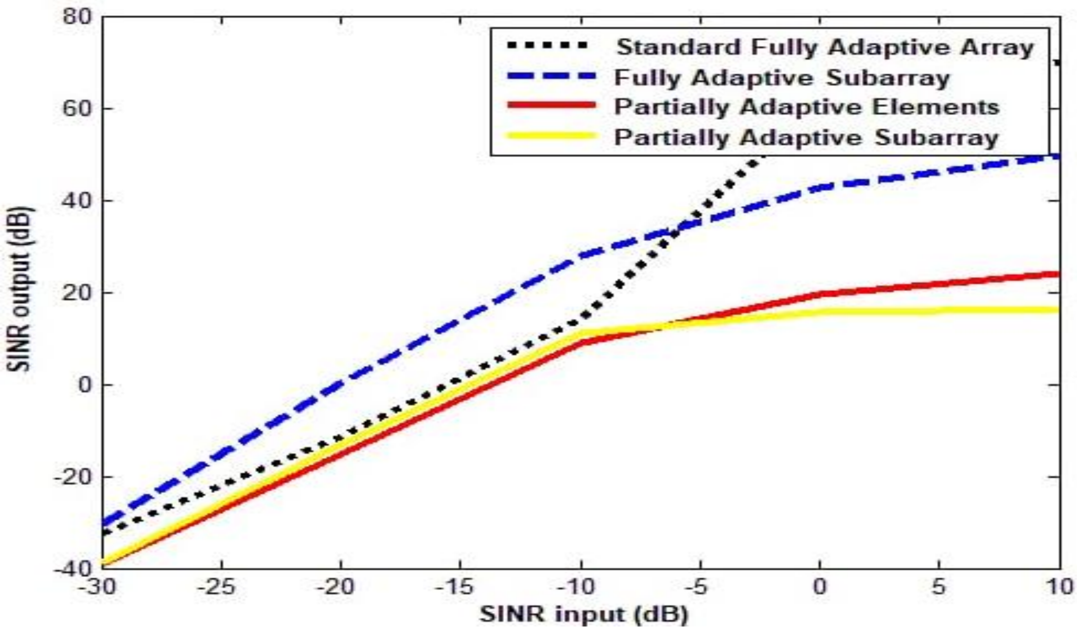


Figure.3.45. Variations of the output SINR versus input SINR with 80 elements.

3.6.3.4 Analysis of the Array Patterns

The simulation result illustrates that as the antenna array element goes on increasing from 12 to 80, the beam width becomes narrow and the number of side lobe goes on increasing .But level of these side lobes is low compared to those generated by small number of elements. It is found that all the array configurations have the ability to place deep and accurate nulls at the interfering directions without any distortions in the array patterns. Also, note that they are able to steer the main beam toward desired signal direction.

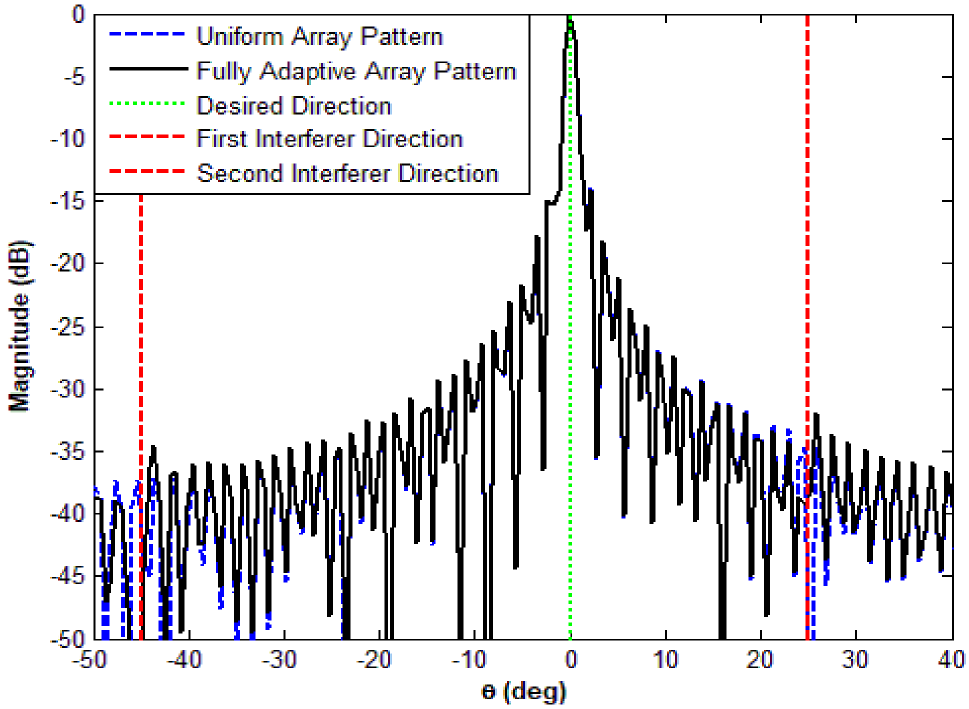


Figure.3.46. Array patterns of fully adaptive array.

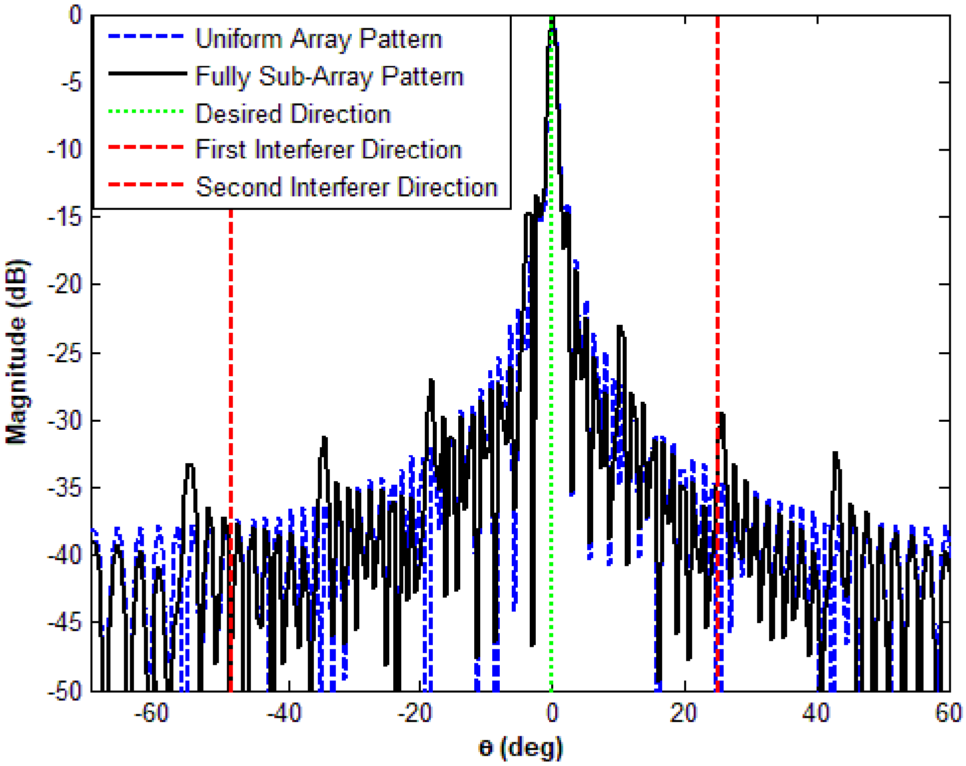


Figure.3.47. Array patterns of the fully adaptive subarray.

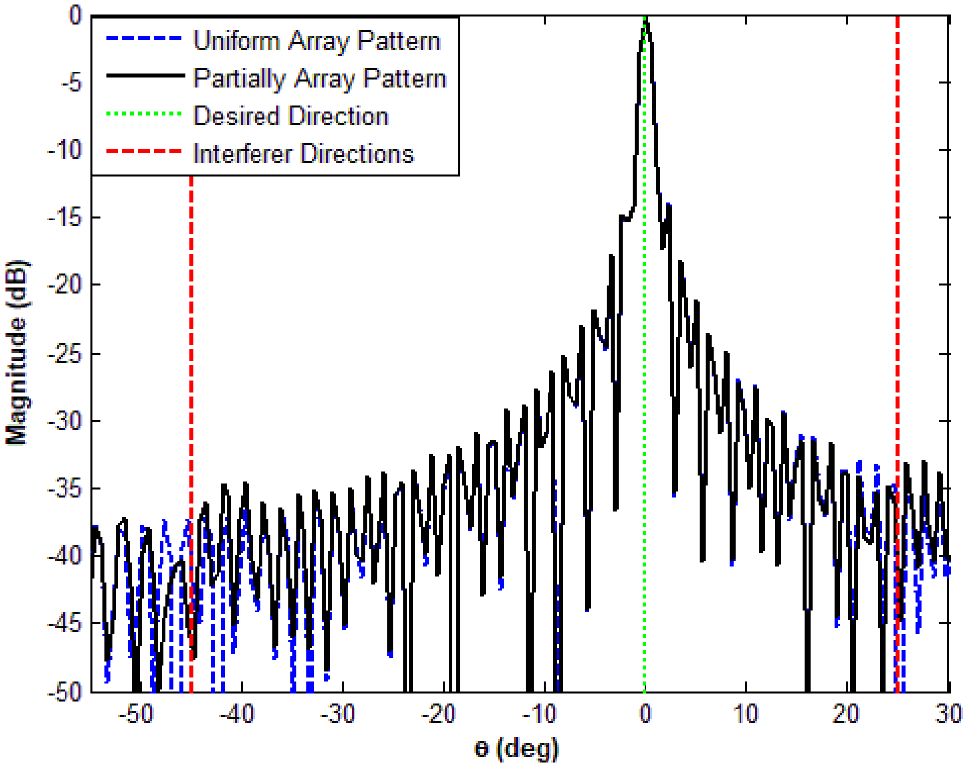


Figure.3.48. Array patterns of the partially adaptive element**.**

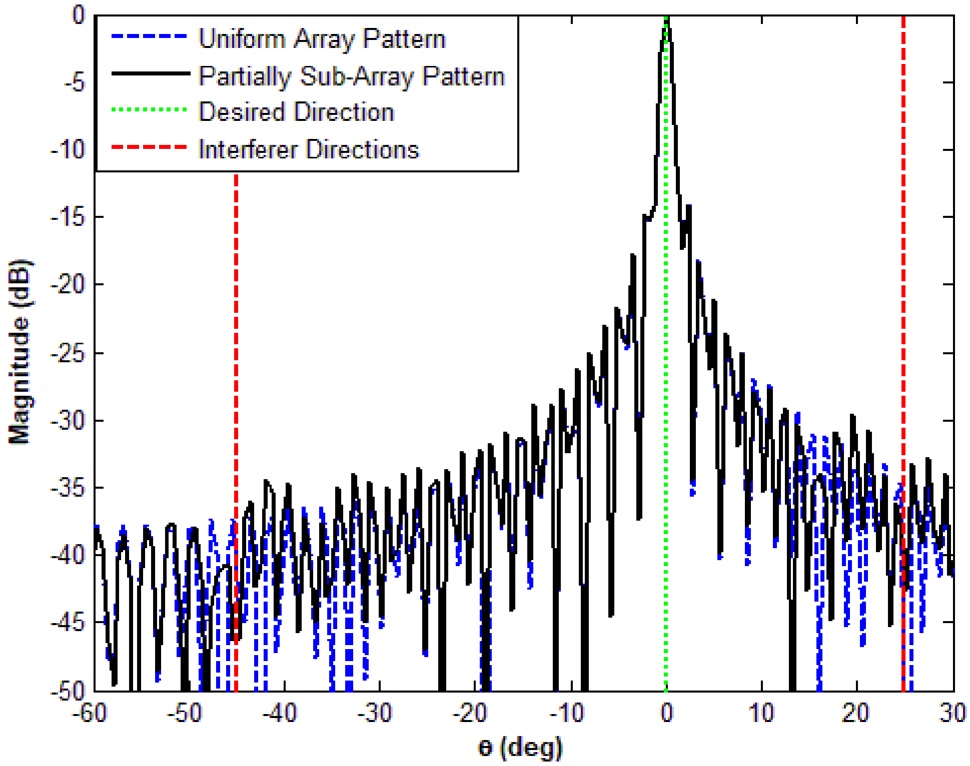


Figure.3.49. Array patterns of partially adaptive subarray**.**

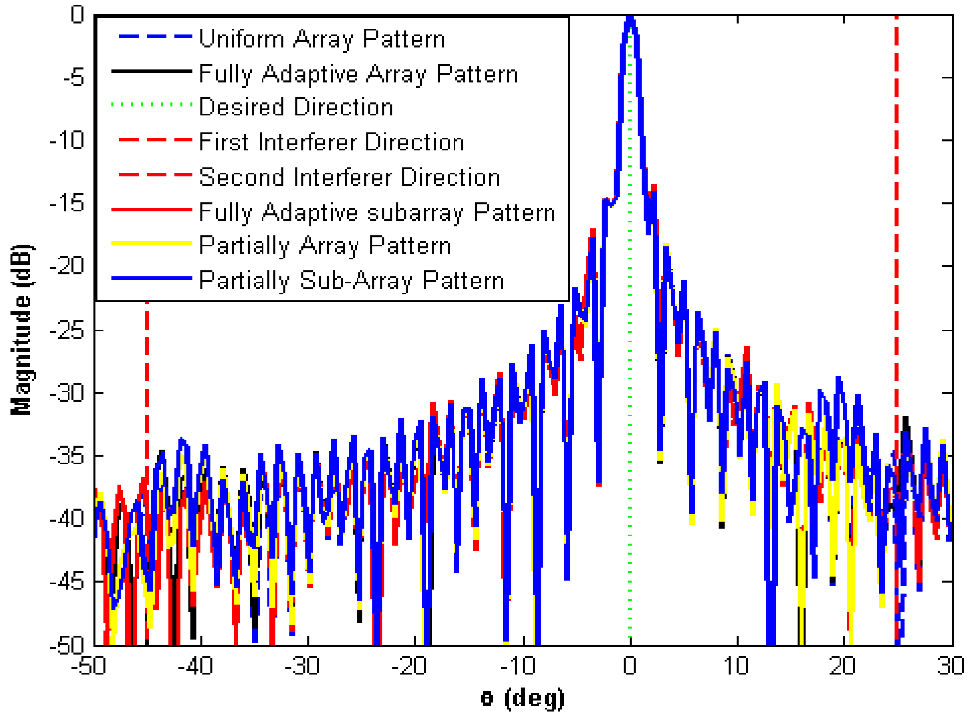


Figure.3.50. Array patterns of different array configurations for two interferer signals with 80 elements.

Finally, the table 3.2 shows a comparison in term of directivity, SINR, and interference cancellation with respect to different number of array elements.

Table 3.2. A comparison between different number of array elements.

No. of elements	12	40	80
Directivity	Low	Medium	High
SINR	Low	Medium	High
interference cancellation	Medium	Medium	High

The above table results are inferred from the array patterns, and SINR mentioned figures. The table shows the array with 80 elements performs better than 12 and 40, and this is because the number of adaptive elements is more in the array with 80 elements.

CHAPTER FOUR

HARDWARE REALIZATION AND VERIFICATION

4.1 Introduction

To experimentally validate the performance of the proposed adaptive array and its usage in 5G applications, the operating frequency was chosen at 3.5 GHz to design the considered antenna arrays that are aimed to be deployed in the 5G base station applications. For simplicity of implementation we choose to use a simple linear antenna array. Its amplitude weights are adapted by the adaptive algorithm and the final weights after the convergence have been applied in the design. The number of the considered array was chosen to be only 4 elements. Their amplitude weights were optimized by the adaptive controller to get an array radiation pattern with a single desired null at 48^o. The resultant amplitude weights were [0.48 1 1 0.48]. Thus, the feeding network of the first and last elements are only needed to be controlled. The design was built using CST 2019 version and on the FR4 substrate which are shown in sections 4.2 and 4.3. Finally the radiation pattern of the proposed designe of 4-elements array was examined in the microwave laboratory of the department of Communications Engineering at Nineveh University

4.2 Design And Simulation Result Using CST

To confirm the validity of the proposed adaptive array and to design the considered 4-elements array with found amplitude weights [0.48, 1, 1, 0.48], microstrip lines with unequal width were considered to justify the required excitation weights of the edge array elements. First a 4*1 elements array with corporate feed network using the CST

2019 version is designed. As mentioned, the operating frequency is set to 3.5 GHz to design an array that is most suited for the use in the 5G applications. Figure 4.1 shows a complete design of the proposed antenna array with required corporate feeding network.

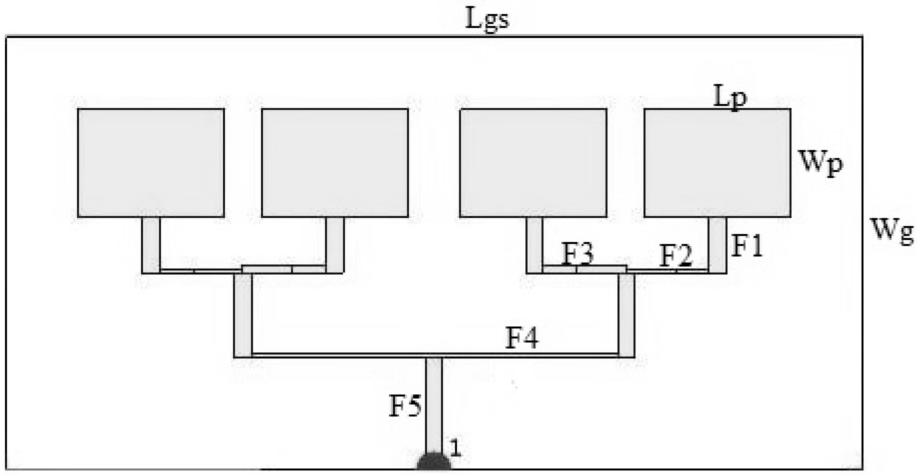


Figure 4.1. Complete design of proposed antenna array.

The design has the following specifications of (226x89.42x1.6) mm^3 of substrate and ground of (226x89.42x0.035) mm^3. Additionally, the required values of the used parameters in the designed 4-elements adaptive antenna array are illustrated in the Table (4.1).

Table 4.1. Parameter values of the proposed array.

TL	F1 W*L	F2 W*L	F3 W*L	F4 W*L	F5 W*L	WP	Lp
Value (mm^2)	**3 x 10**	**0.7 x 14.82**	**1.4 x 14.82**	**0.7 x 31**	**3 x 20**	**18.96**	**26.08**

In the proposed design, split-tee power divider is used as shown in the Figure 4.2. The characteristics impedance of the microstrip transmission line are calculated using the following equations [42,43].

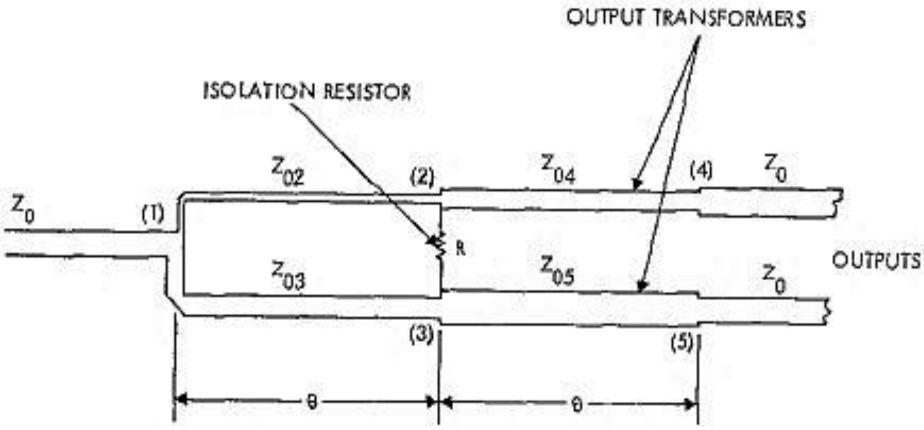


Figure. 4.2. Design equation for the split-tee power divider.

$$\frac{power\ at\ port\ 4}{power\ at\ port\ 5} = \frac{1}{K^2} \quad [4.1]$$

$$Z_{02} = Z_0\sqrt{K(1+K^2)} \quad [4.2]$$

$$Z_{04} = Z_0\sqrt{K} \quad [4.3]$$

$$Z_{03} = Z_0\sqrt{\frac{1+K^2}{K^3}} \quad [4.4]$$

$$Z_{05} = \frac{Z_0}{\sqrt{K}} \quad [4.5]$$

$$R = Z_0\,\frac{1+K^2}{K} \quad [4.6]$$

The S_{11} results for the proposed design is shown in 4.3, the radiation pattern of the designed 4-elements array is also measured as shown in Figure 4.4. The width and the length of the microstrip antenna are obtained using the equations in [4]. The width of the feeding network are calculated using the following equations.

when $\left(\frac{W}{H}\right) < 1$ [4.7]

$$\boldsymbol{\varepsilon}_e == \frac{\varepsilon_{r+1}}{2} + \frac{\varepsilon_{r-1}}{2}\left[\left(1+12\left(\frac{H}{W}\right)\right)^{\frac{-1}{2}} + 0.04\left(1-\left(\frac{W}{H}\right)\right)^2\right] \quad [4.8]$$

when$\left(\frac{w}{H}\right) \geq 1$ [4.9]

$$\varepsilon_e == \frac{\varepsilon_{r+1}}{2} + \frac{\varepsilon_{r-1}}{2}\left(1 + 12\left(\frac{H}{W}\right)\right)^{\frac{-1}{2}} \quad [4.10]$$

To calculate the line width of the microstrip, the following equation is used [44].

$$w = \frac{7.48*h}{exp\left(z_0\frac{\sqrt{\varepsilon_e+1.41}}{87}\right)} - 1.25 * t \quad [4.11]$$

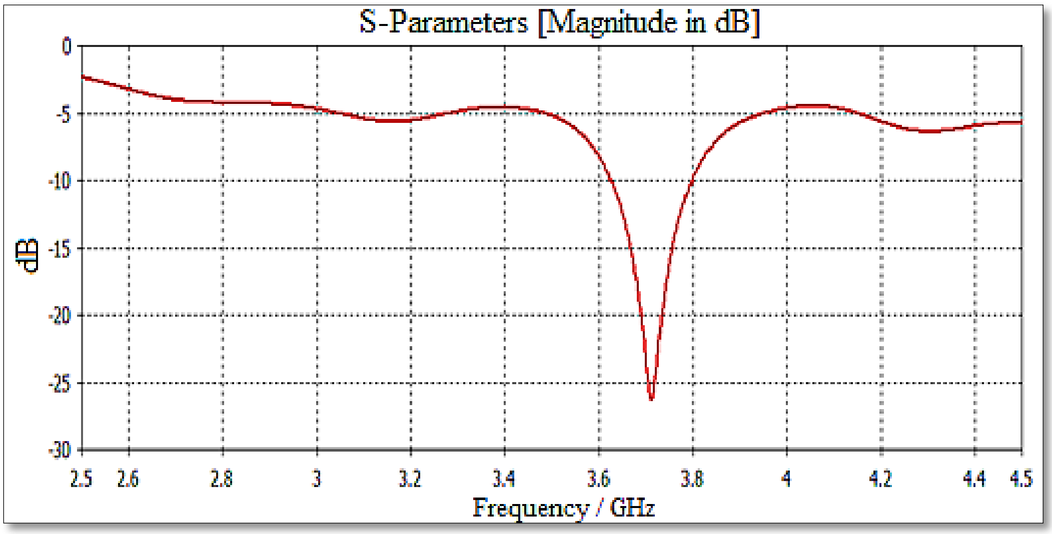


Figure. 4.3. Simulated S11 for the proposed antenna array.

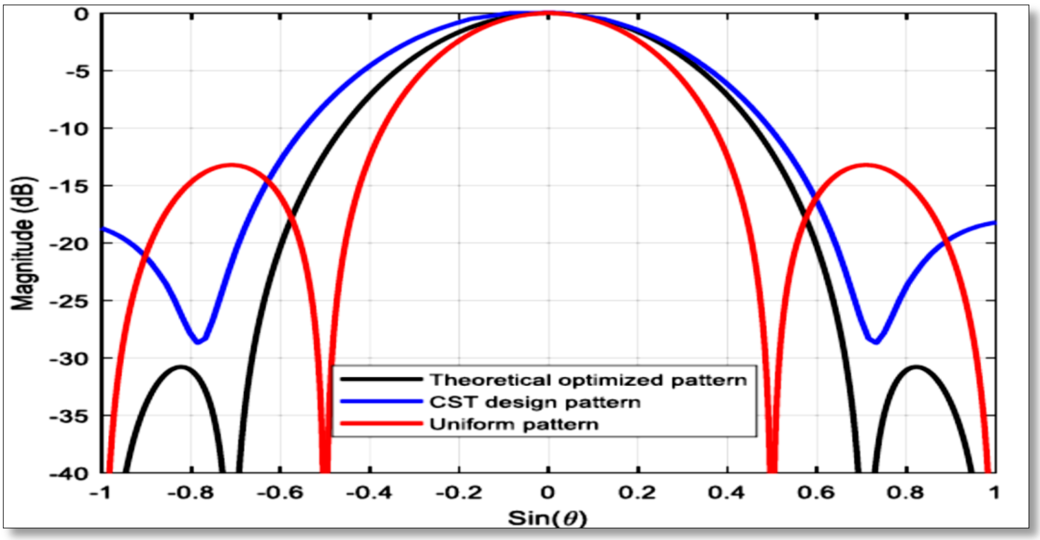


Figure 4.4. Simulated radiation patterns by CST for the designed 4 elements array.

It can be seen that the simulated results of the radiation pattern and the simulated one are in a good agreement and the required null at 48^o at both sides of the array pattern was accurately placed. This fully confirms the effectiveness of the proposed array.

4.3 Fabrication and Testing

In this section, the proposed adaptive 4-elements array is fabricated and tested to characterize and verify the simulation results. generally, to manufacture antenna arrays, several fabrication methods can be used to create PCB antenna array boards [45] . One of the most commonly used antenna array manufacturing techniques is PCB etching [46]. The design of the antenna was built on FR4 substrate

The antenna array fabrication process needs precision and focusing to avoid changes in the shape of the designed arrays because these changes will affect the performance and characteristics of the printed antennas. Among these changes and influences are human errors during the manufacture, such as errors in the array dimensions when manufacturing, or incorrect welding, which is the main cause of frequency shifting. The proposed array is examined in the microwave laboratory of the department of Communications Engineering at the Nineveh University. designs were built using

4.3.1 Measurements Settings

Several laboratory instruments were used to take the practical measurements of the proposed designs after fabricating process. The most important laboratory devices used are Spectrum Analyzer (SA), Signal Generator (SG), and some of accessories such as coaxial cables, SMA connectors, adapters, and so on. Figure 4.5 shows set of laboratory devices that were used in this work.

Figure 4.5. Laboratory devices.

Figure (4.6) illustrates the practical method for linking devices together in the laboratory to measure the radiation pattern of printed array designs.

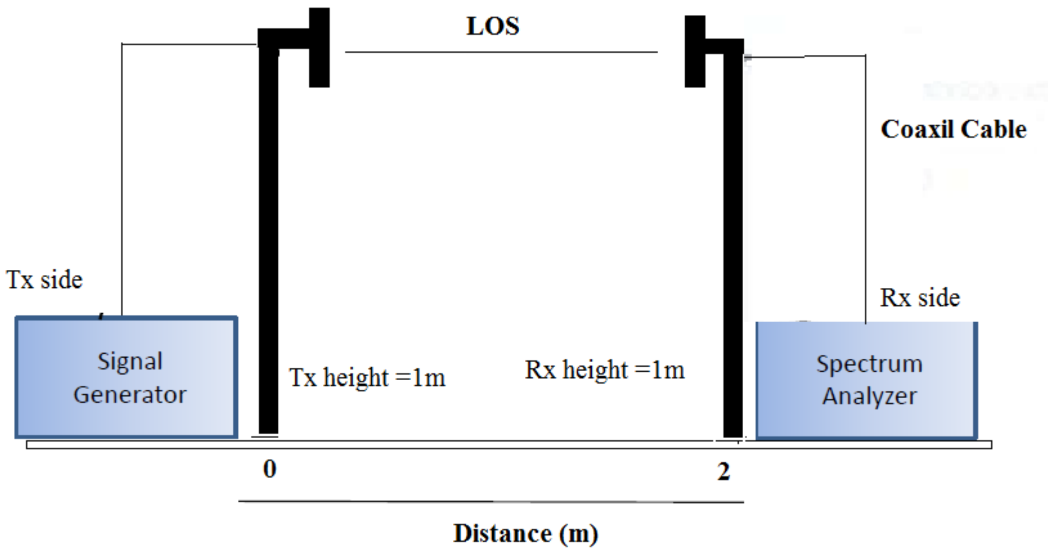
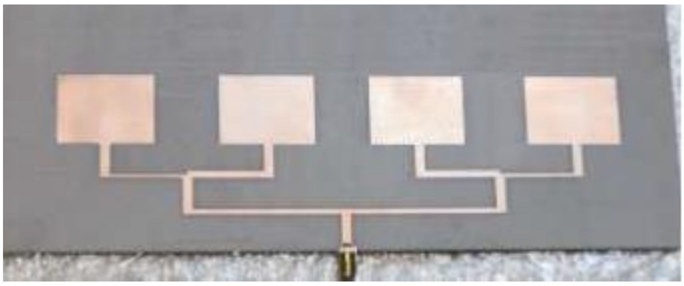


Figure 4.6. Structure of the practical implementation for the radiation pattern measurements.

4.3.2 Fabrication Of Proposed Design

In the proposed array, four rectangular microstip patches were fabricated and measured. Figure 4.7 shows the proposed printed antenna array. The microstip patches were fabricated using PCB etching technique through a fiber laser Computer Numerical Control (CNC) machine.



A: Front view

B:Back view

Figure 4.7. Prototype of the proposed array

4.3.3 Measurements

The following measurements are taken in the microwave laboratory of the department of Communications Engineering at the Ninevah University. The architecture shown in Figure 4.78 is utilized to measure the radiation pattern of the printed antenna array**.** As shown in Figure 4.6 below two identical antenna arrays are used in the transmitter and receiver**.** Additionally, the distance between transmitter and receiver has been made greater than the far field distance (R), which is determined based on the following equation:

$$far\ field\ (R) \geq \frac{2D^2}{\lambda} \quad [4.12]$$

Where D is the maximum dimension of the antenna array, and λ is the wave length in free space. Figure (4.9) shows the radiation pattern of the proposed antenna array in terms of simulated and practical results. It is evident from this figure that there is a good convergence between the simulation and the practical results.

Figure 4.8. Measurement of the radiation pattern in the lab.

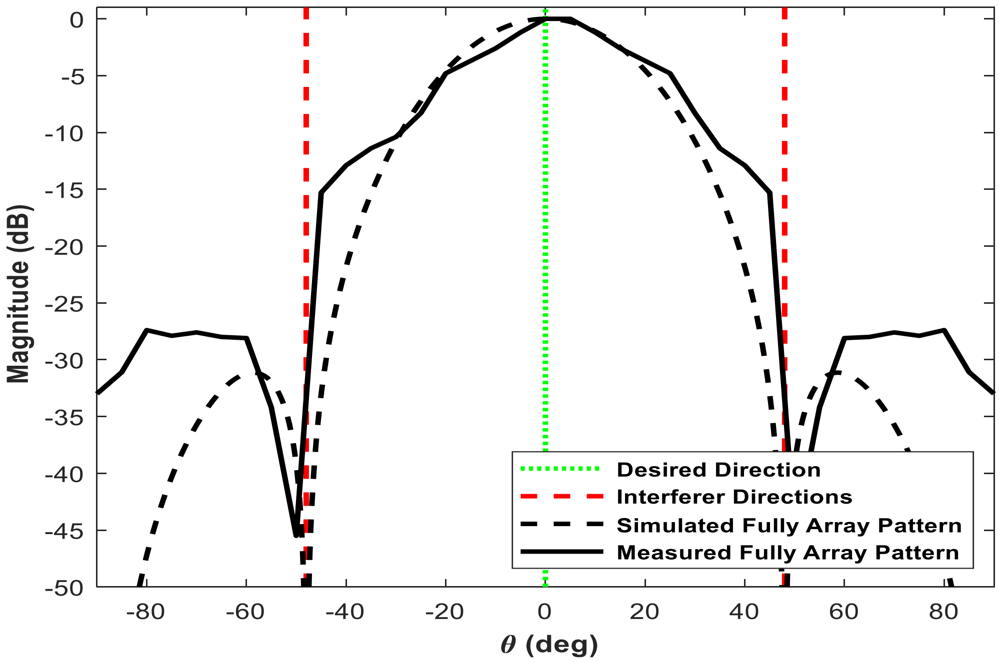


Figure 4.9. Simulated and measured radiation pattern.

CHAPTER FIVE

CONCLUSIONS AND FUTURE WORKS

5.1 Conclusions

An adaptive antenna array has been broadly employed in a variety of applications. Since it is considered as one of the most promising solutions for interference suppression in the crowded spectrum environment of the wireless communication systems such as 5G and beyond. An adaptive antenna system must be employed in such applications for getting better performance and suppressing the interfering signals. The interference suppression can be achieved by properly reshaping the array patterns of the antenna arrays and steering the desired nulls into directions of undesired interfering signals to improve the signal to interference plus noise ratio (SINR) at the system output.

In general , some difficulties can be raised when it comes to practical implementation of adaptive arrays such as high complexity weighting network due to deployment a large number of adaptive controllers which result in a low convergence speed of the used adaptive controllers. Therefore, this dissertation has introduced three new array configurations to simplify the weighting network and at the same time to increase the convergence speed of the adaptive system while providing satisfactory array performance. The proposed array configurations have been named as: regular adaptive subarrays, partially adaptive array elements and partially adaptive irregular subarrays. The performances of these three new configurations have been compared with that of the conventional adaptive fully array.

In the regular adaptive subarrays configuration, subarrays have been formed equally by dividing all the array elements into several equal subarrays and each subarray contains a certain number of the array elements. While in the second proposed configuration which has been named as partially adaptive elements, only a certain number of the array elements have been chosen to be adaptive and the remaining elements have been made constant. The last proposed configuration which has been called as partially adaptive irregular subarrays where in this configuration the adaptive elements are further divided into smaller partially adaptive subarrays for the purpose of achieving more reduction in the feeder network complexity, better improvement in the convergence speed of the optimizer, and at the same time maintaining a good performance for interference suppression.

The concluding remarks about the three proposed configurations are explained in the following points.

1. The results of the proposed configurations have been indicted that the proposed configurations reach the converging state after less number of iterations compared to the standard fully adaptive array. However, the partially adaptive irregular subarrays reaches a converging state with more reduction in the number of iterations compared to other proposed configurations as the number of adaptive element is reduced to a minimum in partially adaptive irregular subarrays.
2. According to the convergence speed, it has been shown that the proposed configurations outperform the standard fully adaptive array. Compared to all proposed configurations, the partially adaptive irregular subarrays configuration has the fastest convergence speed with the condition that the number of

adaptive elements exceeds the interference signals. The fastest convergence speed has been obtained because the number of adaptive elements has decreased compared to other proposed configurations.

3. It has been noted that system noise increases as the number of antenna array elements increases, and total MSE tends to be almost the same for the specified antenna element values.
4. It has also been observed that even with fewer adaptive elements, the proposed configuration can still provide acceptable SINR at their outputs, which fully confirms the effectiveness of the proposed configurations.
5. It has been found that all proposed configurations can place deep and accurate nulls at the interfering directions without any distortions in the array patterns.
6. It has been shown that the interference signals can be reduced to -20 dB, which is quite enough for modern 5G and beyond wireless communication systems.

5.2 Future Works

In this section, a list of potential future research directions is presented

1. The proposed configurations were based on the least mean squares (LMS) algorithm as a controller for the array weighting network, as a future work different adaptive algorithms may be investigated under the same array configurations to get lower mean square errors and faster convergence speed.
2. In the proposed configurations, the step size value was constant, therefore an investigation of variable step size value

can be considered as a future work with the same proposed configurations.

3. It is also possible to extend this work to other planar array geometries such as circular array, rectangular array, or even conformal array that can be used in the curvature surfaces.
4. A real time adaptive array beamforming for the 5G applications may be implemented on any platform such as Digital Signal Processing (DSP) kit, Arduino, or any other kit.

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PUBLICATION

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الخلاصة

أحد الحلول الواعدة لمنع التداخل في بيئة الطيف المزدحمة لأنظمة الاتصالات اللاسلكية مثل G5 وما بعده هو استخدام الانظمة الهوائيات التكيفية. ومع ذلك ، قد تنشأ بعض المشاكل العملية عندما يتعلق الأمر بالتنفيذ الفعلي لهذه الهوائيات ، مثل شبكة التغذية عالية التعقيد الناتجة عن استخدام العديد من وحدات التحكم التكيفية ، مما يؤدي إلى تباطئ السرعة للخوارزميات التكيفية. لذلك ، في هذه الرسالة، تم اقتراح ثلاثة تكوينات جديدة للمصفوفات التكيفية. التكوين الأول عبارة عن مصفوفات فرعية تكيفية منتظمة. في هذا التكوين ، يتم تقسيم جميع عناصر المصفوفة بالتساوي إلى مصفوفات فرعية متعددة ، ولكل مصفوفة عدد متساوٍ من عناصر التحكم. بعد ذلك ، يُطلق على التكوين الثاني عناصر تكيفية جزئيًا حيث يتم تكييف عناصر معينة من المصفوفة فقط ، بينما تكون العناصر المتبقية ثابتة. يسمى التكوين الأخير المصفوفات الفرعية متكيفة جزئيًا الغير منتظمة، حيث تنقسم العناصر التكيفية إلى مصفوفات فرعية اصغر ذات تكيف جزئي. توفر التكوينات المقترحة العديد من الفوائد على المصفوفات التقليدية المتكيفة بالكامل ، بما في ذلك تقليل عدد العناصر القابلة للتحكم ؛ وبالتالي ، تم تسريع سرعة الخوارزمية بشكل كبير دون الحاجة إلى مصفوفة ذات تكوينات معقدة والتي بدورها تقلل من تكاليف التصنيع. من ناحية أخرى ، أظهرت نتائج المحاكاة فعالية التكوينات المقترحة من حيث سرعة التقارب، وتقليل إشارات التداخل إلى أكثر من ‎-20‎ ديسيبيل ، وهو أمر مناسب لشبكات الجيل الخامس وأنظمة الاتصالات اللاسلكية المستقبلية. أخيرًا ، تمت محاكاة مصفوفة الهوائي التكيفي باستخدام برنامج CST 2019 وتم تصنيعها من أجل التحقق من فعالية العمل المقترح.

إقرار المشرف

أشهد بأن هذه الرسالة الموسومة (**دراسة وتصميم المصفوفة التكيفية لإلغاء التداخل في تطبيقات الجيل الخامس**) والمعدة من قبل الطالب (**رشا بشار محمد بشير**) تمت تحت اشرافي وهي جزء من متطلبات نيل شهادة الماجستير في هندسة الاتصالات.

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المشرف: أ.د. جعفر رمضان محمد

التاريخ: / /2022

إقرار المقوم اللغوي

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

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التوقيع:

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التاريخ: / /2022

إقرار لجنة المناقشة

نشهد بأننا أعضاء لجنة التقويم والمناقشة قد اطلعنا على هذه الرسالة الموسومة (**دراسة وتصميم المصفوفة التكيفية لإلغاء التداخل في تطبيقات الجيل الخامس**) وناقشنا الطالبة (رشا بشار محمد) في محتوياتها وفيما له علاقة بها بتاريخ / / 2022 وقد وجدناها جديرة بنيل شهادة الماجستير-علوم في اختصاص هندسة الاتصالات.

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التاريخ: / /2022

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اجتمع مجلس كلية هندسة الالكترونيات بجلسته المنعقدة بتاريخ : / / 2022
وقرر المجلس منح الطالبة شهادة الماجستير علوم في اختصاص هندسة الاتصالات.

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التاريخ: / /2022

التوقيع:

رئيس مجلس الكلية: أ.د. خالد خليل محمد

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دراسة وتصميم المصفوفة التكيفية لإلغاء التداخل في تطبيقات الجيل الخامس

رسالة مقدمة من قبل

رشا بشار محمد

الى
مجلس كلية هندسة الالكترونيات
جامعة نينوى
كجزء من متطلبات نيل شهادة الماجستير
في هندسة الاتصالات

باشراف
أ.د جعفر رمضان محمد

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