PERFORMANCE ANALYSIS OF ADAPTIVE LINEAR ARRAY

A Thesis submitted in partial fulfillment of the requirements for the award of Degree of

Bachelor of Science in Electrical and Electronic Engineering

by

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Certification

This is to certify that this thesis entitled "**Performance Analysis of Adaptive Linear Array**" is done by the following students under my direct supervision and this work has been carried out by them in the laboratories of the Department of Electrical and Electronic Engineering under the Faculty of Engineering of Daffodil International University in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering. The presentation of the work was held on 11 January 2020.

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List of Abbreviations

SLL	sidelobe level
MSLL	maximum sidelobe level
ULA	uniform linear array
UCA	uniform circular array
AF	array factor
ESLA	equally spaced linear array
DOA	direction of arrival
AOA	angle of arrival
SNR	signal to noise ratio
SINR	signal to interference plus noise ratio
HPBW	half-power beamwidth

FNBW	first null beamwidth
CBF	conventional beamformer
DBF	digital beamformer
dB	Decibel
LMS	least mean square
ALMS	augmented least mean square
RLS	recursive least square
SMI	Simple matrix inversion
CG	Conjugate gradient method
CM	Constant modulus
SOI	signal of interest
TELA	Taylor excited linear array
CELA	Chebyshev excited linear array
ALMS	augmented least mean square

List of Symbols

Θ	azimuth angle
Φ	elevation angle
D	distance between array elements
B	phase constant
Λ	Wavelength
M	Step size
$[].^{*}$	complex conjugate
$[].^{T}$	Transpose
$[].^{H}$	complex conjugate transpose
Π	mathematical constant
$e^{[].}$	exponential function
$\sum$	summation operator
S	steering matrix

T	Time
f	Frequency
k	wavenumber
N	number of array elements
I	identity matrix
ω	angular frequency
R	correlation matrix
x(t)	all the signals induced on all elements
y(t)	beamformer output
w_n^*	complex weight for nth antenna element
W	weight vector
W_c	weight vector for conventional beamformer
T	time delay
a_n	excitation coefficients

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ABSTRACT

In modern communication networks, the smart antenna has been one of the most applied technologies. Instead of conventional antennas, Smart antenna, which is also called a digitally beam-formed array. Antenna beamforming system offers high guidance, narrow beamwidth, small side-lobes, point-to-point patterns, and preferred-pattern features. There is much application of the fastest algorithms like Satellite communication, Terrestrial communication, RADAR, SONAR, Hydrology, Climatography, Ecology, etc. There is a requirement in radar to fastest object detection which depends on the fastest converging method. If the converging method is fast we will detect the object as fast as possible. Especially adaptive beam-forming is required where signals are dynamically rich; the angle of arrival of which is changing continuously over time. It has been a challenge to maintain an effective convergence rate and a low mean distortion of quadrature error for adaptive beamforming. In this thesis, several adaptive techniques are analyzed to determine the fastest adaptive algorithm and low mean distortion of the square error. For the fastest convergence, the ALMS adaptive beamforming is proposed. Extensive numerical simulation tests are used to verify the proposed strategy.

CHAPTER 1

INTRODUCTION

1.1. Overview of Antenna Array System

Wireless communication is the fastest-growing segment of the communication industry by any measure. Some common wireless communication advantages include improved efficiency, increased flexibility, wide coverage area, user mobility, low cost, etc.[1]. The world has been influenced by wireless communication in many important ways, such as health care, environmental protection, entertainment, social media and education, defense and security, telephony, space technology, etc. The antenna is one of the main components of the wireless communication network. It is the basic component for electro-magnetic signal transmission and receiving.

An antenna is simply a component of radiation. It is a tool that converts electrical power to waves of radio and vice versa[2]. The dictionary of Webster describes antenna as "a typically metallic device (as a rod or wire) for radiating or receiving radio waves." The IEEE Standard Definitions of Antenna Terms (IEEE Std 1445–1983) defines an antenna or aerial device as "a means of radiating or receiving radio waves." Single-Element antenna performance is somewhat limited. Narrow beamwidth, low sidelobes, point-to-point and preferred-coverage pattern characteristics of antenna arrays are used to obtain high directivity. An antenna array is an assembly of individual radiating antennas in an electrical and geometric configuration[1-2]. Antenna arrays have replaced conventional dipole, monopole, or folded dipole antenna in recent years. There are a variety of antenna components in the antenna array. The main features of an array are that, relative to dipole antennas, it offers a higher angle, lower SLL and also wider beamwidth[3]. The idea of an antenna array was used in the 1940s for the first time in military applications[4]. This innovation was important in wireless communications as it enhanced the patterns of antenna reception and transmission used in these systems. The array's characteristics depend primarily on the number of elements, the form of component used, the arrangement of elements and the geometry of the array[5-7]. The main goal of the beamforming antenna array is to successfully transmit (or receive) a signal in the desired direction in space. Antenna array supports different methods to tailor the characteristics of the radiation to the system requirements.

Beamforming is sorting spatially. Spatial filtering is a signal processing method used in sensor arrays to send or receive directional signals rather than to transmit the signal in all directions[8]. Normally, an array collects and processes spatially propagating signals from a certain direction to acquire useful information. For this reason, we plan to combine the signals from all the sensors in a linear manner with the coefficients in order to approximate the transmitted data from a specific direction. This procedure is known as beamforming as the weighting mechanism emphasizes signals from a particular direction while attenuating signals from other directions that can be considered to cast or form a beam[9-10]. Through beamforming, an array processor steers a beam to a certain direction by measuring a properly weighted sum of the individual sensor signals just as a finite impulse response (FIR) filter produces an output (at an interest rate) which is the weighted sum of time samples[8]. Looking at a beamformer as a selective frequency filter is convenient. Therefore, filtering techniques can be applied to applications for the sensor array for the beamformer design. Array processing is a signal processing environment with powerful tools to extract information from signals that are obtained using a variety of sensors. The aim of storage arrays is to obtain as much as environmental data. The analysis of array signals focuses in particular on the signals emitted by propagating waves[11-13].

Beamformers can be classified into traditional beamformers and adaptive beamformers, depending on the weighting values being set or not. Conventional beamformers use a fixed set of weightings and time delays to combine the sensor signals within the array, usually using only the position of the signal of interest (SOI) relative to the sensor array[14]. An array must, however, deal with unnecessary signals coming from other directions, which may prevent it from successfully extracting the SOI for which it has been built. Under this condition, to reject unwanted signals from other directions, the array must change its response to the received signals. The resulting array is an adaptive array and the correct adaptive beamformer updates the weighting by optimizing a certain output criterion that is subjected to different constraints. Adaptive beamformers have greater interference resolution and rejection than traditional beamformers. Over the past decades, there has been a great deal of effort to develop adaptive beamformers[15]. There are many types of adaptive algorithms for antenna array, such as the least mean square (LMS), the least mean augmented square (ALMS), the least square recursive (RLS), the conjugate gradient (CG), the constant module (CM), etc[16-17].

Several adaptive antenna array beamforming applications and implementations make their position very quickly in modern life. Large applications are in satellite and terrestrial networking for adaptive beamforming. They are vastly used in RADAR and SONAR[18]. For photography and media, these methods are used. We have contributions in many areas in the medical field, such as hearing aids, fetal heart monitoring, hyperthermia of the skin, etc. We are also used in geography, seismology, meteorology, hydrology, topography, climatology, and many other variables in the environment[20]. All of these developments have increased the development, user-friendliness, and efficiency of modern communication networks.

1.2. Literature Review

The antenna has a very rapid and evolving sector and has contributed over the past 70 years to the communication system. Much research has been done to improve antenna array performance, and there is still plenty of opportunity for further research.

The first paper on improving the performance of arrays by component excitation control dates back to the mid-1940s. Dolph[21] studied linear large arrays and the optimized relationship between beamwidth and sidelobe level was first established. Taylor [22] discovered another way of synthesizing of line source antenna array to give a radiation pattern of narrow angular beamwidth of the main lobe and low side lobes.

In 1960, Widrow and Hoff came up with adaptive switching circuits [23]. They mainly introduced the least mean square (LMS) algorithm in a stationary and non-stationary environment. They showed an analysis of convergence rate and stability for the LMS algorithm. Later these theories were more improved by Ungerboeck [24]. Frost discussed adaptive array processing in a linearly constrained environment [25]. In 1976, Widrow improved his own work using LMS in the stationary and nonstationary environments [26].

On the other side, adaptive techniques got developed by various researchers. Most of them worked with the improvement of linearly constrained adaptive algorithms [27,15&28]. Around 2000, Godara discussed various adaptive methods like RLS, CG, CM along with the LMS algorithm [17]. Then Haykin and Kailath broadly discussed adaptive filtering [29].

Despite the popularity and effectiveness of the BP algorithm, it has serious problems such as a slow rate of convergence and initial weights [30-31]. To overcome this problem we analyze various algorithms to find the fastest algorithm. Neural network training algorithms are commonly based on optimization theory. These algorithms find optimized weights in order to minimize error[32]. Dr. U D Dalal focuses on the adaptive beamforming approach used in smart antennas and Recursive Least Square (RLS) adaptive algorithm used to compute the complex weights by own simulation[33].

In the present time, The most challenging task in the phased array radar system is the mitigation or suppression of noise and interferences to enhance the useful signal in radar received signals. Multiple solutions have been proposed by researchers for suppression of unwanted signals or interferences which have highly degraded the overall system performance [34]. They use LMS and RLS algorithms to solve this problem. But in our paper, we discuss ALMS which can quickly mitigate interference and error than LMS and RLS. Jalal discusses the performance of an adaptive linear array employing the new RLMS algorithm, which consists of a recursive least square (RLS) section followed by a least mean square (LMS) section. The performance measures used are output and input signal-to-interference plus noise ratios (SINR), side lobe level (SLL).

1.3. Objectives

The objectives of this thesis are as follows:

- To observe the radiation pattern of the array.
- To achieve the implementation of adaptive algorithms in a linear array.

- To evaluate the fastest convergent method for linear arrays.
- To detect the object as first as possible.
- To observe the weight and error characteristics for different adaptive algorithms.

1.4. Outline of the Thesis

This work is outlined in the following way. Chapter 2 describes the main ideas and terms used to understand arrays of antennas. This addresses the antenna array's fundamental parameters. Together with a proposed system, Chapter 3 presents an adaptive algorithm. It discusses three adaptive algorithms which are LMS, ALMS, and RLS. Then it makes several comparisons among the techniques referring to convergence, error, and weight. This thesis paper is concluded in chapter 5. Chapter 5 presents important results and gives a conclusion based on the results. At last, the future points of interest and further possibilities of research on this topic are discussed.

CHAPTER 2

FUNDAMENTALS OF ANTENNA ARRAY

2.1. Introduction

For many users, the antenna arrays are very useful. It is possible to identify the array antenna in many ways. In evaluating antenna efficiency, there are some basic parameters. All of the basics of the antenna array are presented and discussed in this section. Often mentioned in this section are the various types of the array antenna.

2.2. Antenna Array system

An antenna array is a multi-antenna configuration. An array's geometric configuration may be linear, circular, rectangular, and so on. A single element's radiation pattern is relatively broad and each element provides low gain value.

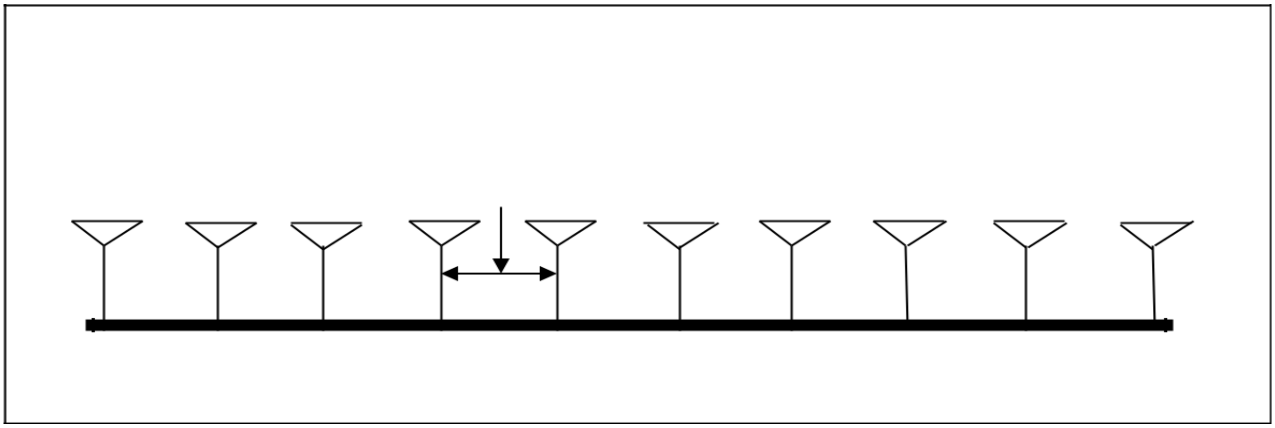


Fig. 2.1. Ten elements & half-wavelength spacing uniform linear array

It is important to model high-directivity antennas for very long-distance communication purposes in many applications. This can be achieved by the antenna's electrical size. In this modern age, the antenna array is the only way to create further contact with the directive.

2.2.1. Characteristics of Antenna Array

The components of an exhibit are indistinguishable. It isn't important yet it is frequently down to earth. The individual components of a cluster might be of any structure (wires, gaps and so forth). The absolute field of the exhibit is dictated by the vector expansion of the fields emanated by the individual components. The current in every component is equivalent to that of the separated component. It is important that the field from the array elements intervene constructively in the desired directions and canceled interference between each other destructively in order to provide very directive. An array antenna's radiation pattern is as below.

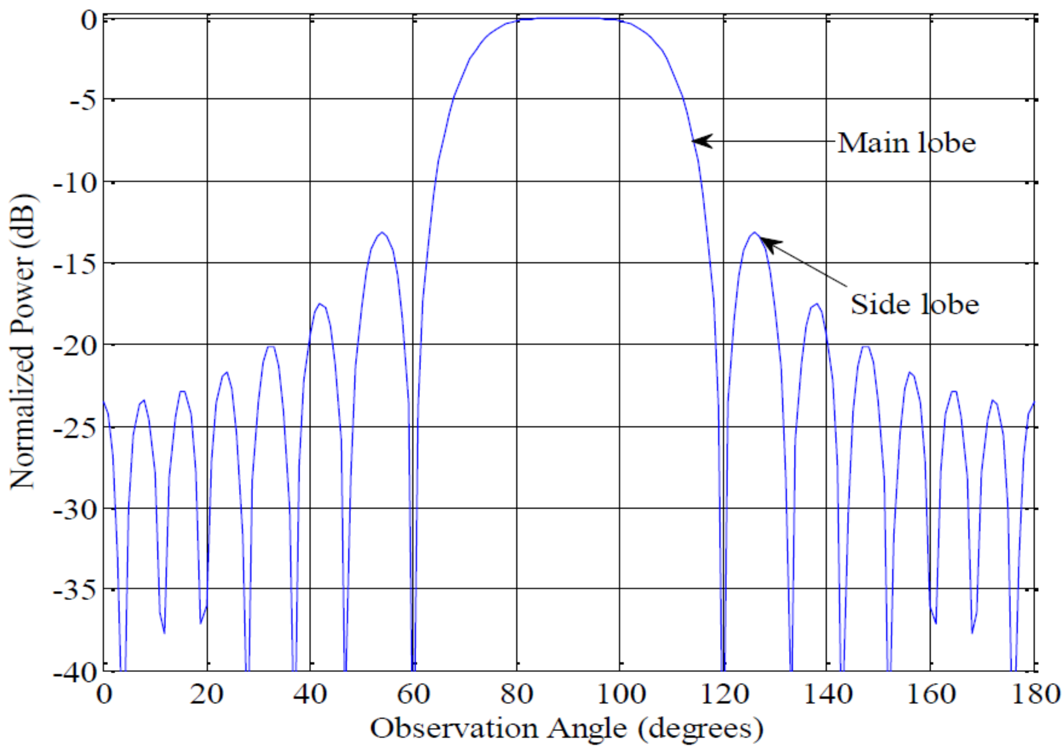


Fig. 2.2. Power pattern of a 15 element-half wavelength spacing antenna array

To form an array's overall pattern, we must change the following parameters,

- The geometrical configuration of the overall array of any kind.
- The relative displacement between elements.
- The excitation amplitude of the individual elements.
- The excitation phase of individual elements.
- The relative pattern of the individual elements.

2.2.2. Why use Antenna Array

The major benefits of the antenna array are as follows:

- **Overall gain:** In the antenna array, the overall gain is increased rather than a single element.
- **Diversity reception:** A received signal's power level can vary significantly with small distance changes. Array provides the reception of diversity and combines all signals to achieve maximum signal.
- **Cancelation of interference:** Antenna array can destructively cancel interference in the desired direction.
- **Main beam steering:** the antenna array provides beam-steering properties for steering the signal in a specific direction.
- **Arrival Direction (DOA):** The incoming signal DOA may be calculated by antenna array rather than a single component.
- **SINR:** The interference signal plus noise ratio (SINR) in the antenna array is maximized. So for more guideline interaction, it can be easy to calculate how much noise & interference is to be reduced.

2.3. Parameters of Antenna Array

Antenna performance is analyzed by examining different parameters. These parameters describe the complete antenna array description. Not all of them are necessary to specify the array performance characteristics. The main antenna array parameters are,

- Directivity or Gain
- Half power beamwidth (HPBW)
- First null beamwidth(FNBW)
- Sidelobe level (SLL)
- Radiation pattern
- Beam steering
- Array factor

2.3.1. Directivity

Directivity of an antenna defined as the ratio of radiation intensity distributed across all directions in a given direction from the antenna to radiation intensity. The average frequency of the radiation is equal to the total antenna-divided energy of the antenna. The direction of the peak radiation dose is assumed if the direction is not defined. In the mathematical form[1]

$$D = \frac{U}{U_0} = \frac{4\pi U}{P_{rad}} \qquad (2.1)$$

If the direction is not defined, it means the direction expressed as the peak radiation intensity (maximum directivity).

$$D_{max} = D_0 = \frac{U_{max}}{U_0} = \frac{4\pi U_{max}}{U_0} \qquad (2.2)$$

Where D=directivity (dimensionless), D_0 =maximum directivity (dimensionless), U=radiation intensity (W/unit solid angle), Umax =maximum radiation intensity (W/unit solid angle), U_0=radiation intensity of isotropic source (W/unit solid angle), Prad =total radiated power (W).

2.3.2. Half-Power Beamwidth (HPBW)

The beamwidth of a pattern is known as the angular distance on the opposite side of the peak pattern between two equivalent points. There are a variety of beamwidths in antenna design. The angle between the two directions in which the radiation frequency is a half-value of the beam is referred to as HPBW in a plane containing the direction of a beam's height.

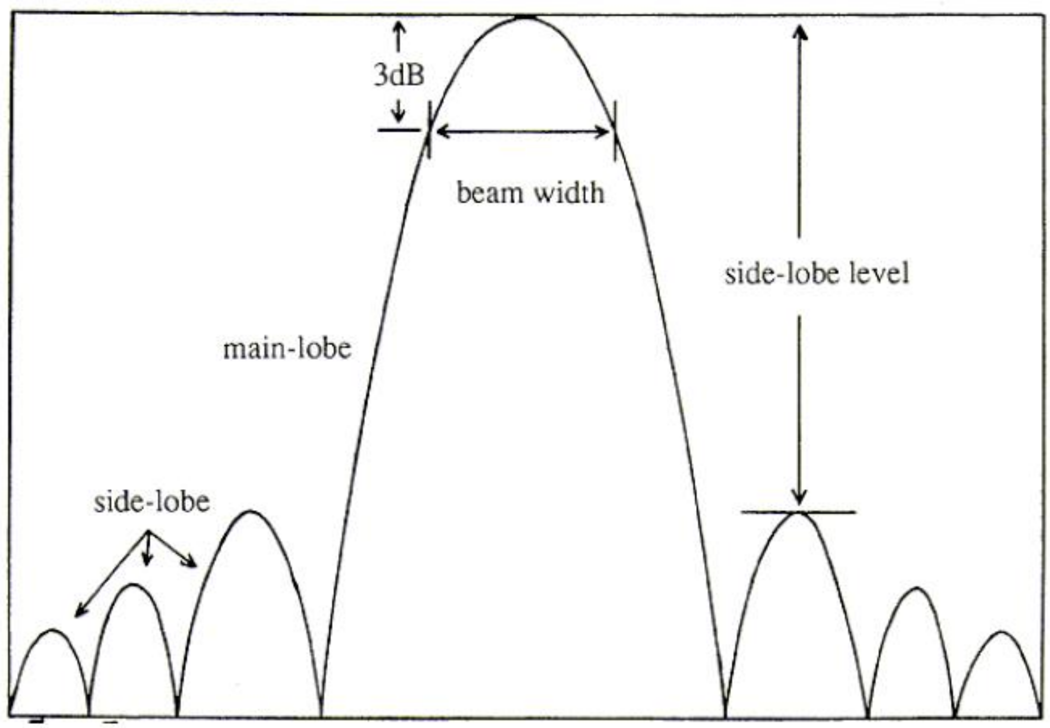


Fig. 2.3. HPBW of antenna radiation pattern [1]

Because U(x) reflects the power pattern, the half-power beamwidth is equivalent to half its peak value.

$$U(\theta) = COS^2(\theta)COS^3(\theta) \quad (2.3)$$

At HPBW, $\theta = \theta_h$ & U(θ) = 0.5 Therefore , HPBW =2θ_h

In practice, the term beamwidth usually refers to HPBW without any other classification. An antenna's beamwidth is a very significant merit statistic and is often used as a trade-off between it and the rate of the side lobe; that is, as the beamwidth decreases, the side lobe increases and vice versa. Therefore, the antenna's beamwidth is used to define the antenna's resolution capabilities.

2.3.3. First-Null Beamwidth (FNBW)

Another important beamwidth is the angular separation between the pattern's first nulls and is known as the First-Null Beamwidth(FNBW). Figure 2.4 illustrates both HPBW and FNBW.

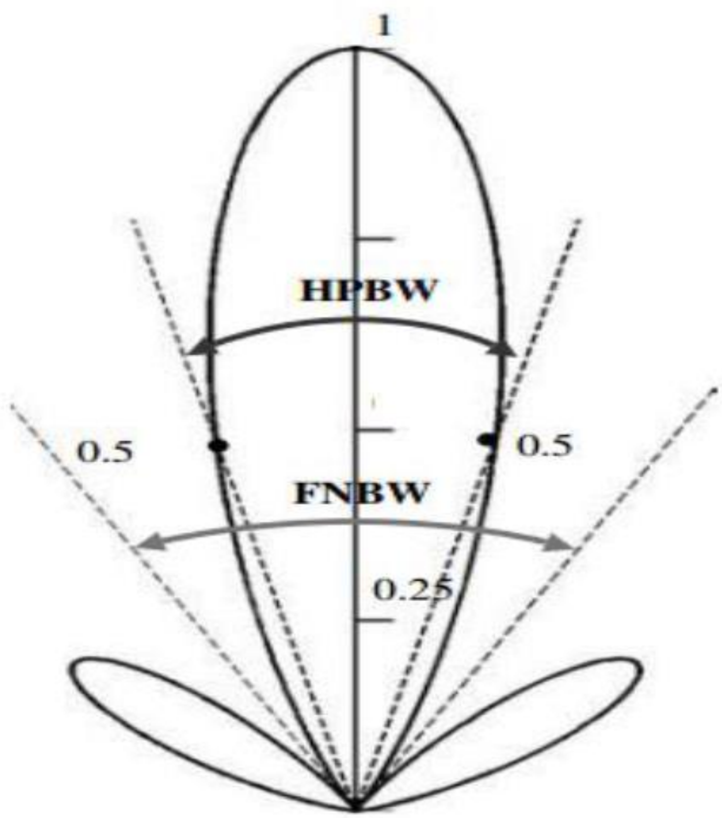


Fig. 2.4. HPBW & FNBW of radiation pattern [1]

To find the first-null beamwidth (FNBW), U (θ)equals to zero. This can be also expressed as

$$U(\theta) = COS^2(\theta)COS^3(\theta) \tag{2.4}$$

At HPBW, $\theta = \theta_h$ & U(θ) = 0.5 Therefore , HPBW =2θ_h

2.3.4. Side Lobe Level (SLL)

The sidelobe level (SLL) varies from the highest main lobe level to the first minor lobe. SLL is one of the main parameters of the performance analysis of the array. SLL is kept as low as possible with a more guideline communication system. SLL is connected with HPBW. It can be expressed as,

$$SLL \propto \frac{1}{HPBW}$$

In the various antenna array, SLL is special. The weighting of the set also depends. SLL is required for some applications. Sometimes the array model is the primary consideration.

2.3.5. Radiation Pattern

An antenna radiation pattern or antenna pattern is defined as a function of space coordinates as a mathematical function or a graphical representation of the antenna radiation properties. The radiation pattern has been calculated in the far-field area in most cases and is interpreted as a function of the directional coordinates. Radiation properties include the density of the energy flux, frequency of the radiation, the strength of the field, direction, phase or polarization. The amplitude field pattern is considered a trace of the obtained electrical (magnetic) field at a constant radius. On the other hand, an amplitude power pattern is called a map of the spatial variance of the power density along a constant radius.

The field and power patterns are often measured in terms of their maximum value, resulting in the normalized field and power patterns. In addition, the power pattern is usually plotted on a logarithmic scale or more generally in decibels (dB).

- ❖ Typically, field pattern (in linear scale) represents a plot of the magnitude of the electrical or magnetic field as a function of angular space.
- ❖ Power pattern is usually a plot of the square of the magnitude of the electrical or magnetic field as a function of angular space.

❖ Power pattern(in dB) as a function of angular space reflects the strength of the electrical or magnetic field, in decibels.

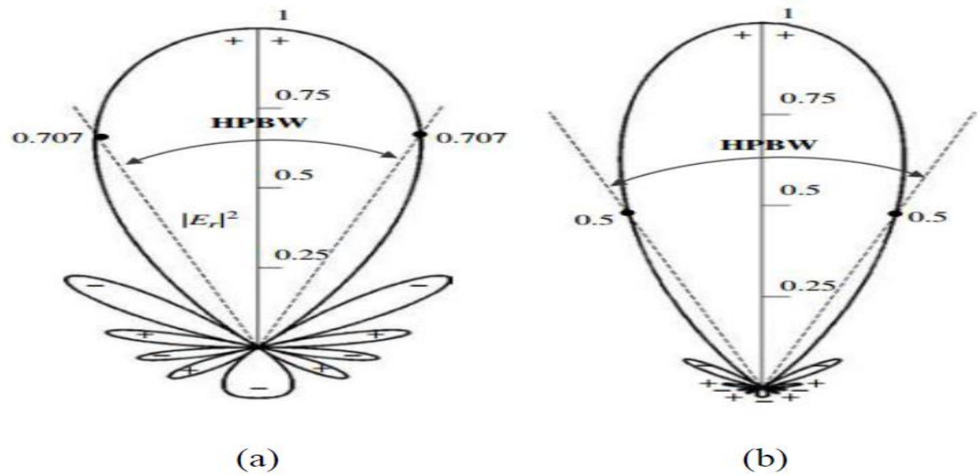


Fig. 2.5. Normalized radiation pattern [1]

To demonstrate this, the two-dimensional normalized field pattern (plotted in linear scale), power pattern(plotted in linear scale) of a 10-element linear antenna array of isotropic sources, with a spacing ofd=0.25λbetween the elements, are shown in Fig. 2.5.

The plus(+) and minus(−) signs in the lobes reflect the relative polarization of the amplitude between the different lobes in this and subsequent cycles, which shifts (alternates) when the nulls are crossed. Figure 2.7 displays the logarithmic scale (dB) energy sequence. The value of the pattern to locate the points where the pattern exceeds its half-power (−3 dB points) compared to the maximum value of the pattern

- Field pattern at 0.707 value of its maximum, as shown in **Fig. 2.5(a)**
- Power pattern (in a linear scale) at its 0.5 value of its maximum, as shown in**Fig. 2.5(b)**
- Power pattern (in dB) at−3dBvalue of its maximum, as shown in **Fig. 2.6**.

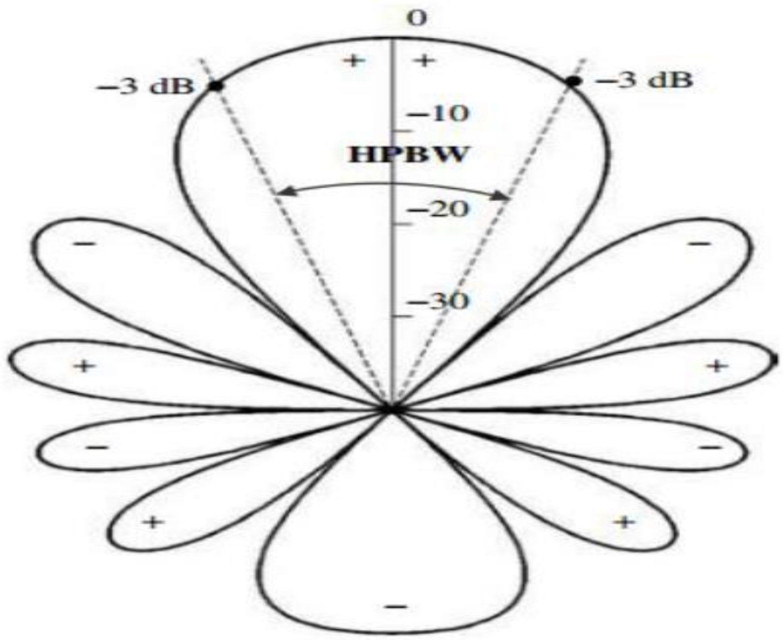


Fig. 2.6. Power pattern in dB of a ten element 0.25λ spacing array [1]

These three patterns give the two half-power points the same angular separation. In practice, in a sequence of two-dimensional patterns, the three-dimensional pattern is calculated and registered.

2.3.6. Beam Steering

The beam can be directed in different directions for a given array by rotating the array mechanically. This is referred to as automatic steering. Beam steering can also be achieved by correctly slowing the signals before being combined. The process is referred to as electronic steering, and there is no mechanical movement. When merging, the phase shifters are used to adjust the signal phase for narrowband signals. The required delay can also be achieved by inserting different lengths of coaxial cables between the elements of the antenna and the combiner.

Changing the variations of these cables ' different lengths leads to different direction of pointing. Switching to guide beams in various directions between different combinations of beam-steering networks is sometimes referred to as beam switching. Throughout digital processing, the signals from different elements can be sampled, processed and summed to form beams after sufficient delays. The delay needed by selecting samples from various elements so that the samples selected are taken at different times. Each sample is delayed by multiple integers of the sampling interval; therefore, when using this technique a beam can only be pointed in selected directions.

2.3.7. Array Factor (AF)

The array factor depends on the array and weights antenna position used. The antenna array can be optimized to achieve desirable properties through the adjustment of these parameters. For example, a change in weights can control the antenna array.

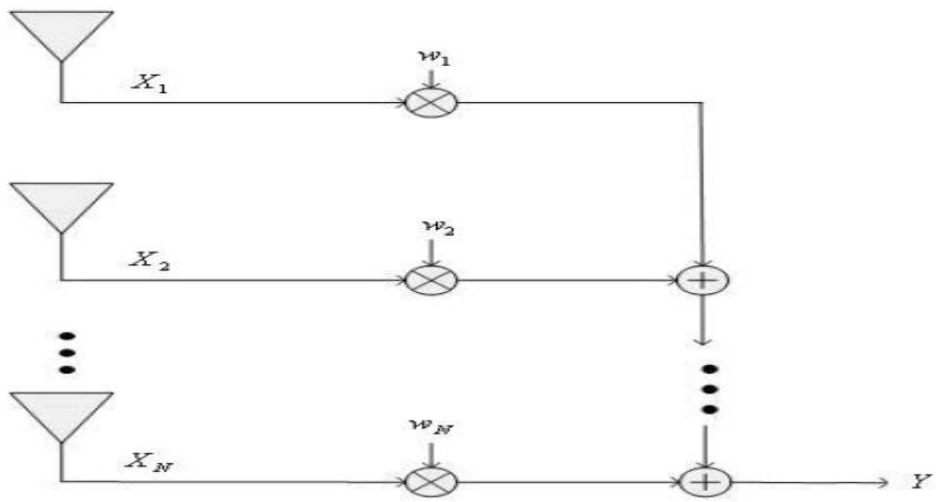


Fig. 2.7. The output of the N-element antenna array using corresponding weights

The figure shows an arrangement for antenna N-element set with its weight. [2.7].

Consider a set of antenna elements N, each with radiation pattern given by R (θ, $\emptyset$). Assuming i element is located at a position given by,

$$r_i = (x_i, y_i, z_i)$$

As per the figure. 2.7 Each component within the array is multiplied by a complex Wi weight and then combined to form the phased output of the array, Y. The antenna efficiency varies depending on the angles at which an incident aircraft wave arrives. The array itself is a space filter in this manner. The input signal is filtered by the arrival angle. The output Y is the function of a wave relative to the set (to bring it in, to give it in). Therefore, the radiation pattern will be the same if the array is transmitted. Now Y can be expressed as

$$Y = R(\theta, \varphi)\left[w_1 e^{-jkr_1} + w_2 e^{-jkr_2} + \cdots \ldots \ldots \ldots . + w_n e^{-jkr_n}\right]$$

$$Y = R(\theta, \varphi) \sum_{i=1}^{N} W_i e^{-jkr_i}$$

$$Y = R(\theta, \varphi) AF$$

Therefore, $AF = \sum_{i=1}^{N} W_i e^{-jkr_i}$

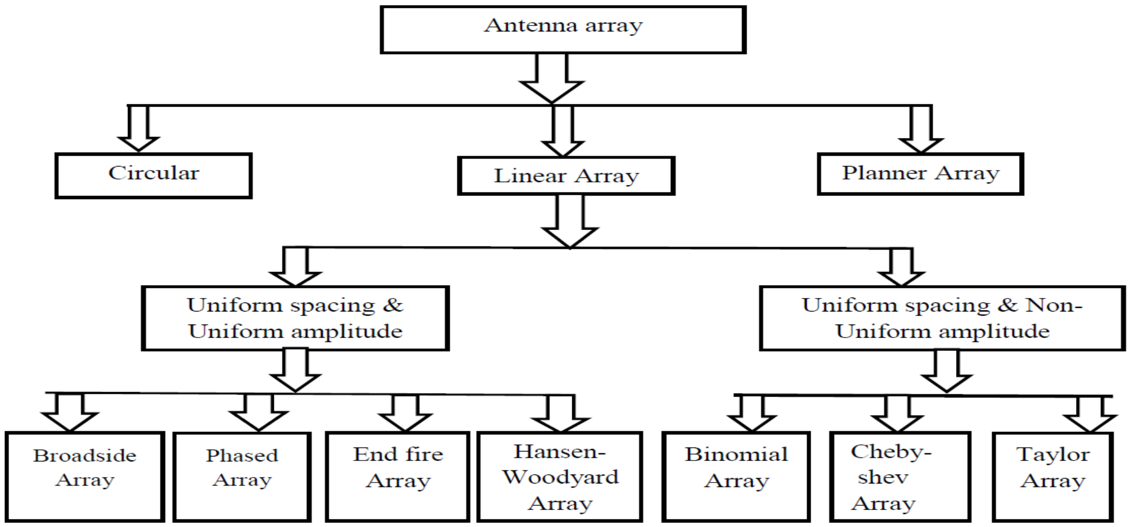
Use the s_k steering Vector to convey the factor of Set. s_k is an L-dimensional complicated vector with answers of all unit power unit L components. The expression is as,

$$S_k = [e^{j2\pi f\tau_1(\theta_k, \varphi_k)}, \ldots \ldots \ldots \ldots \ldots . . e^{j2\pi f\tau_2(\theta_k, \varphi_k)}]$$

So, Array factor is, $AF = W^H S_K$

The Harmitian matrix of weights is denoted by W^H

2.4. Types of Antenna Array



This diagram shows rather than the branches in a circular or planner array of the linear array. The linear array is different based on spacing and amplitude formation. Instead of another two, the linear array has vast applications. These are hereafter described.

2.4.1. Uniform Linear Array

The sequence in which the display elements are arranged either directly or linearly is called a linear array. The same element series is of all the same magnanimity and is referred to as a uniform array, each with a progressive stage. The spacing is uniform in a linear array. Nevertheless, the amplitude can be uniform or not. Fig 2.8 is shown the uniform linear array.

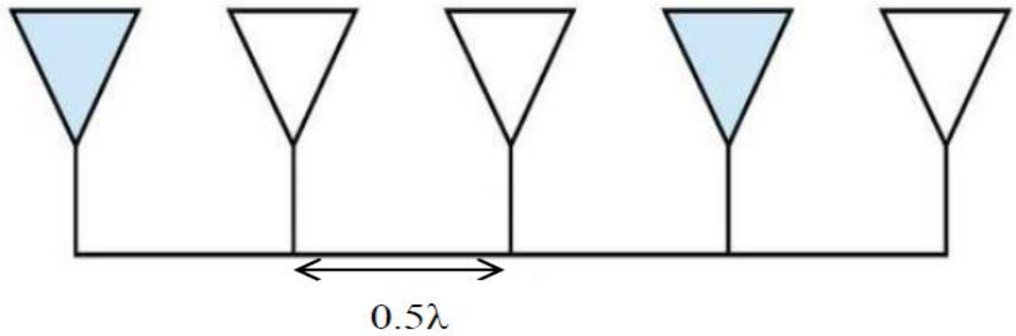


Fig. 2.8. Five-element uniform linear array with a half-wavelength spacing

2.4.2. Uniform Circular Array

The uniform circular array is an array of circular display elements. There are no edge elements in the circular arrays.

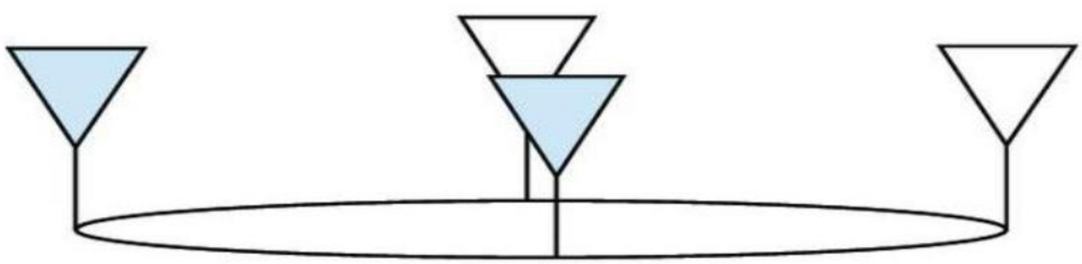


Fig. 2.9. Uniform circular Array

The beam design of a circular array can be electronically rotated without edge constraints. Therefore, the circular arrays can compensate for the effect of mutual interaction by breaking down the excitation array into a set of symmetrical spatial components. Uniform circular array has numerous applications. Some of them are given below,

- Directional finding
- Navigational aid
- Electronic support measures
- Omnidirectional coverage

CHAPTER 3

ADAPTIVE ALGORITHM

3.1. Introduction

Modern beam steered array antennas are called intelligent antennas, where the pattern is shaped according to certain optimum criteria. For a smart array to be sophisticated implies that the beam simply leads towards interest. Smart basically means the antenna radiation performance control. Computer control. Smart models are managed by adaptive algorithms on the basis of certain requirements. These could be the maximization of SIR, the reduction of variance, the reduction of the mean square mistake (MSI), the direction of an interference signal, the annulment of interference signals, or monitoring of the transfer emitter. The following could be used. This process is referred to as adaptive radiation when the algorithms used are adaptive algorithms. Adaptive beamforming is a sub-category of digital beamforming in a more general sense. This section deals with three techniques of adaptation, LMS, ALMS, and RLS, evaluating and comparing performance against certain criteria.

3.2. Conventional And Optimal Beamforming

The signals of each component are multiplied by a complex weight in a traditional antenna array system and summed up to form the output array. Also known as delay and sum beamformer is a conventional beamformer. The weights are of equal value with conventional antenna arrays. The excellent technique allows the signal-to-noise ratio (SNR) to be maximized. Find the N antenna element array device as shown in Fig. 3.1. The first time. Where ' w ' refers to the weight and ' x ' refers in all elements to a signal caused.

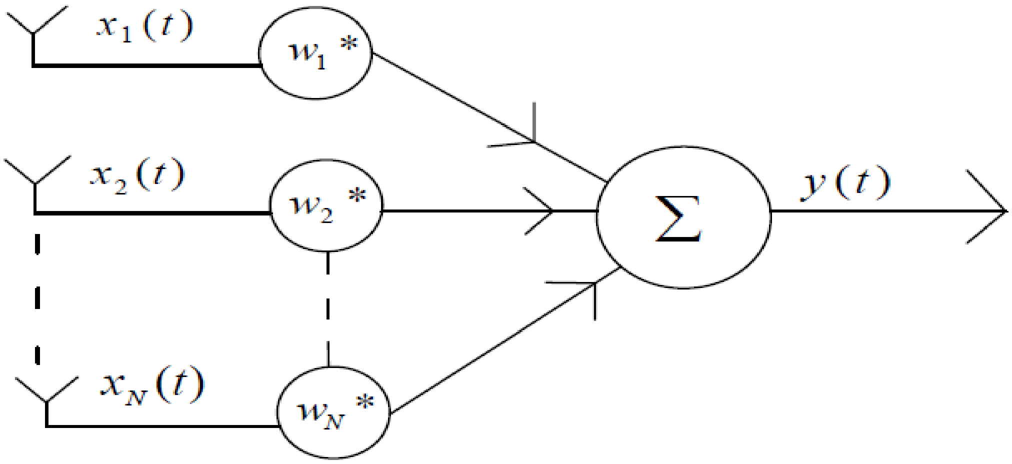


Fig. 3.1. The conventional antenna array system

The figure above shows no pieces such as pre-amplifier, bandpass filters, etc. The set output expression is given by,

$$Y(t) = \sum_{n-1}^{N} W_n{}^* X_n(t) \quad (3.1)$$

Where * is the conjugate complex.

Beamforming is usually carried out independently on each of the sensor signals as shown in the figure. 3.2, a delayed and weighted sensor signal, which is applied to the beamformer output consecutively. The phases are selected to guide the array in a specific direction, called the look direction (direction). With S0 showing the direction of the steering vector, the weights are calculated by

$$W_C = \frac{1}{N} S_O \quad (3.2)$$

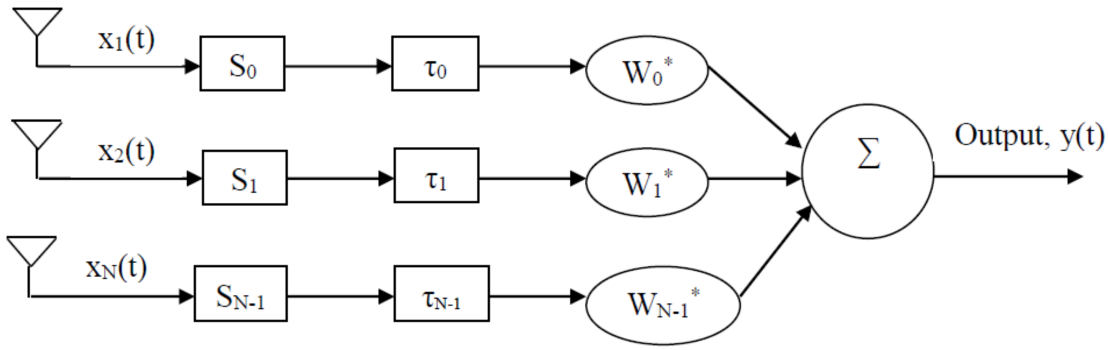


Fig. 3.2. Conventional delay and sum beamforming system

The response of a weight vector W processor to a source in the direction (so, f) is indicated by,

$$y(\theta,\varphi) = W^{H} S(\theta,\varphi) \tag{3.3}$$

The N-dimensional complex vector where S is the steering and steering vector comprises responses of all N elements in the set to a narrowband unit power source. Let S_K denote the steering vector with the origin kth. It is defined as a range of the same elements

$$S_K = [\exp(j2\pi f_0 \tau_1(\theta_k,\varphi_k) \ldots \ldots \ldots \exp(j2\pi f_0 \tau_N(\theta_k,\varphi_k)] \tag{3.4}$$

As the array's response is directed, each directional source is associated with a steering vector. The singularity depends on the geometry of the array. This association The steering vector is unique in each direction for a linear range of elements which is equally spaced with an element spacing more than half of the wavelength. Each part of this vector is of the magnitude of the unit for a number of identical elements. The ith composition period is equal to the phase difference in the origin of the direction vector between the signals produced on the ith element and the reference element. As every segment of this vector indicates the stage delay brought about by the spatial situation of the relating component of the exhibit, this vector is too known as the space vector. It is additionally alluded to as the exhibit reaction vector as it quantifies the reaction of the exhibit because of the source viable.

The reaction of the ordinary beamformer is given by,

$$y(\theta,\varphi) = W^{H}S(\theta,\varphi)$$

$$= \frac{1}{N}S_{O}S(\theta,\varphi) \qquad (3.5)$$

where 'H' denotes the Hermitian matrix.

Ideal beamforming is a procedure to assess an ideal load of radio wire cluster in a wanted heading. This procedure can boost the yield sign to the clamor ratio(SNR). Consider that the commotion condition comprises of the arbitrary clamor of intensity σn 2 and a directional impedance of intensity PI in on look heading. Accept that there is a wellspring of intensity PS in the look heading and that the impedance and the sign are uncorrelated. For this case, the cluster connection framework R is given by,

$$R = P_{S}S_{0}{S_{0}}^{H} + P_{I}S_{I}{H_{I}}^{H} + {\sigma_{n}}^{2}I \qquad (3.6)$$

Where I am a personality framework S_0 and, SI is the guiding vector of sign and impedance. Guiding vector of sign and obstruction can be shaped utilizing condition (2.6) talked about in section 2. Consider an L dimensional complex vector $\hat{\boldsymbol{w}}$ speaks to the obliged weight of the exhibit. The articulation for $\hat{\boldsymbol{w}}$ can be given by,

$$\hat{W} = \mu_{0}R^{-1}S_{0} \qquad (3.7)$$

If the weights of the array are limited to a unit response in the direction of the look,

$$\hat{W}^{H}S_{0} = 1 \qquad (3.8)$$

Thus μ_0 is given by,

$$\mu_{0} = \frac{1}{\mu_{0}R^{-1}S_{0}} \qquad (3.9)$$

The following expression for the weight vector is replaced by the value of μ0.

$$\hat{w} = \frac{R^{-1}S_0}{\mu_0 R^{-1}S_0} \tag{3.10}$$

3.3. Adaptive Beamforming

The most useful and effective stratifying solution is the adaptive beamforming, as the digital transmitter consists only of an algorithm that dynamically optimizes the array design according to the changing electromagnetic environment. The adaptive algorithm takes a step further on the fixed beamformer process and enables continuously updated weights to be calculated. A certain optimization criterion needs to be met in the adaptation process. Different examples of most common optimization techniques include LMS, SMI, RLS, CMA, Conjugate Gradient and a waveform array of different algorithms. In each of the following sections, we will discuss and explain three LMS, ALMS and RLS techniques.

3.3.1. Least Mean Square

A gradient-based approach is the least mean square algorithm. The algorithms based on gradients are expected to have a fixed quadratic surface. When there is an elliptical paraboloid with a minimum of one when the performance surface is a quadratic function of the array weight. A gradient approach is one of the best ways of deciding the minimum. The least is if the gradient is zero. So the optimum Wiener solution as provided is the solution for weights.

$$\bar{W}_{opt} = \bar{R}_{xx}{}^{-1}\bar{r} \tag{3.11}$$

Generally speaking, we do not know the signal statistics, and we have to use the array correlation matrix Rxx and the signal correlation vector r to approximate them for a number of snapshots. These values are given instantaneously as,

$$\hat{R}_{xx}(k) \approx \bar{x}(k)\bar{x}^H(k) \tag{3.12}$$

$$\hat{r}(k) \approx d^*(k)\bar{x}(k) \tag{3.13}$$

Where H is complex conjugate transpose and * is complex conjugate.

We can use a technique called the steepest descent method to estimate the cost function gradient. The steepest descent direction is opposite to the gradient vector. The steepest descent rate can be approximated by weight using the Widrow LMS method. The steepest iterative descent is given as,

$$\bar{w}(k+1) = \bar{w}(k) - 0.5\mu\nabla\bar{w}(J(\bar{w}(k))) \tag{3.14}$$

When we substitute immediate correlation approximations, then we have the following LMS solution,

$$\bar{w}(k+1) = \bar{w}(k) - \mu\left[\hat{R}_{XX}\bar{w} - \hat{r}\right]$$

$$= \bar{w}(k) + \mu e^{*}(k)\bar{x}(k) \tag{3.15}$$

Where, $$e(k) = d(k) - \bar{w}^{H}(k)\bar{x}(k) \tag{3.16}$$

The LMS algorithm overweights the optimum weights of interest when the step size is too large. The underdamped situation is named. If attempted convergence is too fast, the weights differ with optimal weights, but the desired solution will not be tracked accurately. Consequently, a step size in a series that guarantees convergence is imperative. Stability can be shown if the following conditions are satisfied[32].

If the step size is too large, the LMS algorithm overweights the best weights.

There is a name for the under-mounted case. If convergence attempts are too fast, weights vary by optimum weights, but the solution sought is not adequately monitored. A phase in a sequence ensuring convergence is therefore indispensable. The following conditions will demonstrate stability

$$0 \leq \mu \leq \frac{1}{2\lambda_{\max}} \tag{3.17}$$

Where is the largest eigenvalue of $\hat{R}_{xx}$. Since the correlation matrix is positive definite, all eigenvalues are positive. If all the interfering signals are noise and there is only one signal of interest, we can approximate the condition in Eq. (3.17) as,

$$0 \leq \mu \leq \frac{1}{2\ trace\ [\bar{R}_{xx}]} \tag{3.18}$$

3.3.2. Augmented Least Mean Square

In the sense of linear adaptive prediction, we now look at the degree to which commonly linear medium square estimates have advantages over normal linear mean square estimates[42]. We consider a broadly linear adaptive prediction model for which k instantly gives the tap input x(k) to a final impulse response filter of N size,

$$x(k) = [x(k-1), x(k-2), \dots \dots \dots \dots, x(k-N)]^T \tag{3.19}$$

Where T denotes the transpose of a matrix. The augmented tap input delay vector is given as,

$$Z^a(k) = [z^T(k), z^H(k)]^T \tag{3.20}$$

The outcome is as,

$$y(k) = h^T(k)z(k) + g^T(k)z^*(k) \tag{3.21}$$

Where h(k) and g(k) is an immediate approximation of the ideal signal d(k) for the N×1 columns of filter weights k. Here both h(k) and g(k) are variable weights and updated accordingly,

$$h(k+1) = h(k) + \mu e(k)z^*(k) \tag{3.22}$$

$$g(k+1) = h(k) + \mu e(k)z(k) \tag{3.23}$$

We may add an augmented weight vector as below to further simplify the notation,

$$w^{a}(k) = [h^{T}(k), g^{T}(k)]^{T} \tag{3.24}$$

$$w^{a}(k+1) = w^{a}(k) + \mu e(k) z^{a^{*}}(k) \tag{3.25}$$

Where, $w^{a}(k)$ is augmented weight and e(k) is the error. Error is given as,

$$e(k) = d(k) - z^{aT}(k) w^{a}(k) \tag{3.26}$$

The LMS (ALMS) algorithm is a broadly linear extension of standard LMS, completing the derivation. This includes It is easy to implement but takes into account the complete secondary statistics available of complex-valued inputs, and the ALMS algorithm has the same generic format as the CLMS standard.

3.3.3. Recursive Least Square

We can use a recursive algorithm to remove the computational burden and possible singularities. The algorithm can remedy the required matrix and the required vector of correlation. Since the source of the signal may shift or move slowly with the time, the earliest data samples may be highlighted and the most recent ones emphasized. It can be achieved by adjusting formulas (3.12) and (3.13) to neglect the earliest specimens. This is referred to as a weighted calculation.

$$\hat{R}_{xx} = \alpha \hat{R}_{xx}(k-1) + \bar{x}(k) x^{-H}(k) \tag{3.27}$$

$$\hat{r}(k) = \alpha \hat{r}_{xx}(k-1) + d^{*}(k) \bar{x}(k) \tag{3.28}$$

Therefore, potential values can be calculated using previous values to estimate the array correlation and to estimate the vector correlation. This α is the variable that forgets. Often known as the exponential weighting factor is the forgetting factor. α is a positive constant that 0 to α to maximum

1. α is positive. If α= 1, the ordinary lowest square algorithm is restored. α= 1 indicates memory as well. The next measures are the reverse derivative of Rxx. The Sherman Morrison- Woodbury theorem [43] can be used to identify the inverse of Rxx. The SMW theorem is repeated,

$$(\bar{A} + \bar{z}\bar{z}^H)^{-1} = \bar{A}^{-1} - \frac{\bar{A}^{-1}\bar{z}\bar{z}^H\bar{A}^{-1}}{1+\bar{A}^{-1}\bar{z}\bar{z}^H} \tag{3.29}$$

So the inverse of Rxx is,

$$\hat{R}^{-1}{}_{xx}(K) = \alpha\hat{R}_{xx}(k-1) - \alpha^{-1}\bar{g}(k)\bar{x}^H(k)R_{xx}{}^{-1}(k-1) \tag{3.30}$$

Formula (3.30) for the Recursive least square method (RLS) is known as the Riccati formula. Where $\bar{g}(k)$ is given as

$$\bar{g}(k) = \hat{R}_{xx}(k)\bar{x}(k) \tag{3.31}$$

Now a recursion relationship can be established to update the weight vectors.

$$\overline{w}(k) = \overline{w}(k-1) - \bar{g}(k)\bar{x}^H(k)\overline{w}(k-1) + \hat{R}^{-1}{}_{xx}(k)\bar{x}(k)d^*(k) \tag{3.32}$$

We can get the final formula of weights by replacing 3.31 in 3.32.

$$\overline{w}(k) = \overline{w}(k-1) + \bar{g}(k)[d^*(k) - \bar{x}^H(k)\overline{w}(k-1)] \tag{3.33}$$

Recursive formulas make the inverse of the correlation matrix simple to update. Also, the RLS algorithm is much quicker than the LMS algorithm.

3.3.4. Conjugate gradient method

CGM is an iterative method whose goal is to minimize the quadratic cost function

$$J(\overline{w}) = \frac{1}{2}\overline{w}^H\bar{A}\overline{w} - \bar{d}^H\overline{w} \tag{3.34}$$

We may take the gradient of the cost function and set it to zero in order to find the minimum. It can be shown that

$$\nabla_{\overline{w}}J(\overline{w}) = \bar{A}\overline{w} - \bar{d} \tag{3.35}$$

We may employ the method of steepest descent in order to iterate to minimize Eq. (8.119). We wish to slide to the bottom of the quadratic cost function choosing the least number of iterations. We may start with an initial guess for the weights *w*¯ (1) and find the residual *r*¯(1). The first residual value after at the first guess is given as,

$$\bar{r}(1) = -J'\big(\bar{w}(1)\big) = \bar{d} - \bar{A}\bar{w}(1) \tag{3.36}$$

We can next choose a direction vector _ *D* which gives us the new conjugate direction to iterate toward the optimum weight. Thus

$$\bar{D}(1) = \bar{A}^H \bar{r}(1) \tag{3.37}$$

The general weight update equation is given by

$$\bar{w}(n+1) = \bar{w}(n) - \mu(n)\bar{D}(n) \tag{3.38}$$

Where the step size is determined by

$$\mu(n) = \frac{r^{-H}(n)\bar{A}\bar{A}^H\bar{r}(n)}{\bar{D}^H(n)\bar{A}^H\bar{A}\bar{D}(n)} \tag{3.39}$$

We may now update the residual and the direction vector. We can premultiply Eq. (8.122) by −*A*_ and add *d*¯ to derive the updates for the residuals.

$$\bar{r}(n+1) = \bar{r}(n) + \mu(n)\bar{A}\bar{D}(n) \tag{3.40}$$

The direction vector update is given by

$$\bar{D}(n+1) = \bar{A}^H\bar{r}(n+1) - \alpha(n)\bar{D}(n) \tag{3.41}$$

We can use a linear search to determine α(n) which minimizes *J*(¯*w*(*n*)). Thus

$$\alpha(n) = \frac{\bar{r}^H(n+1)\bar{A}\bar{A}^H\bar{r}(n+1)}{\bar{r}^H(n)\bar{A}\bar{A}^H\bar{r}(n)} \tag{3.42}$$

Thus, the procedure to use CGM is to find the residual and the corresponding weights and update until convergence is satisfied. It can be shown that the true solution can be found in no more than *K* iterations. This condition is known as quadratic convergence.

3.4. System model

Originally, a traditional and optimized method is implemented to design the adaptive array system. The adaptive beamforming for the circular array is introduced. The previous sections addressed the standard, efficient beamforming and adaptive beamforming. The device development is supplied with required equations. We give a framework adapted to circular arrays suggested. We offer it here. The array factor equation of circular array is different in terms of array geometry. Like the linear array for improved gain and radiation.

The proposed system is given below,

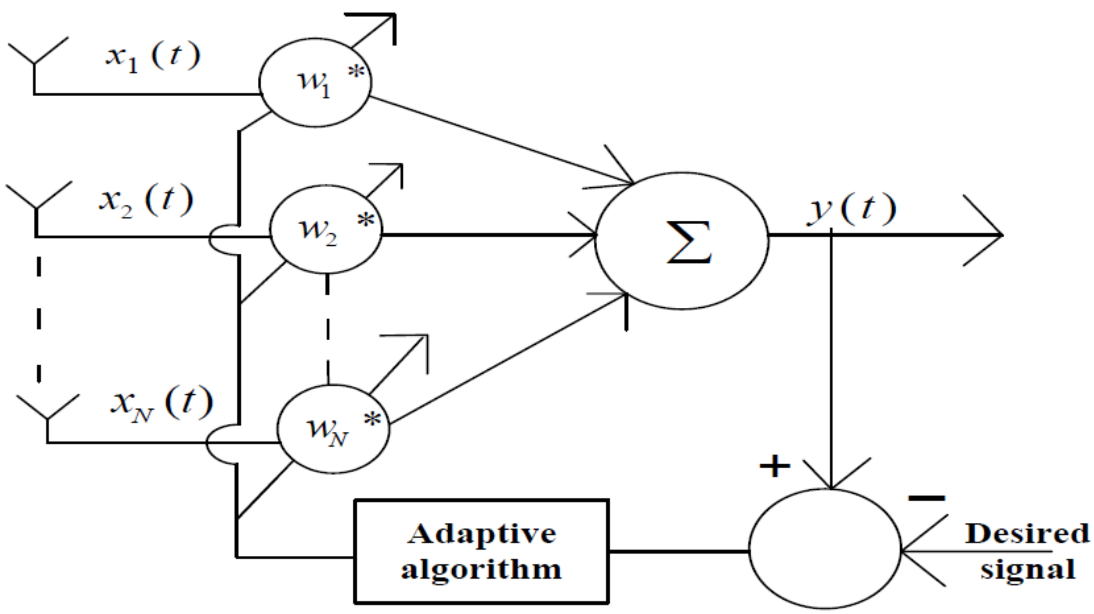


Fig. 3.3. The proposed adaptive antenna array system

A linear array of N elements is used in Figure 3.4. Every element has a weight to be multiplied. Weights have been modified adaptively. The weights are combined to form the output of the array.

The initial output is compared to the signal you like. The real signal and the desired signal are determined by measuring an error. Weight is determined by mistake.

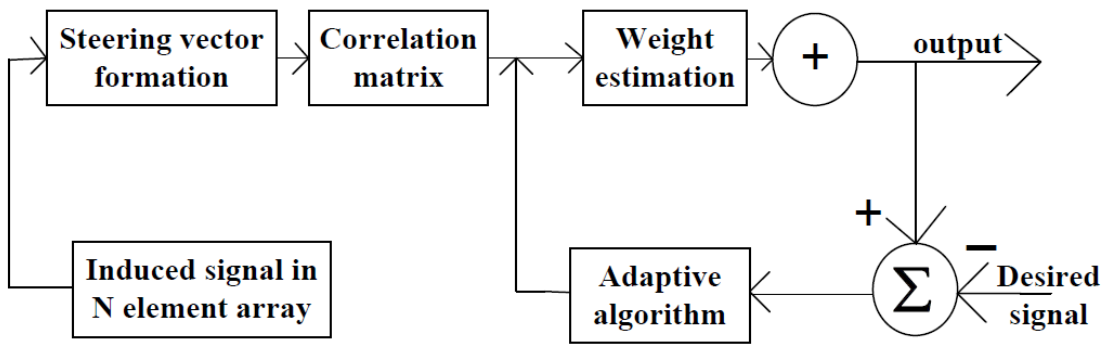


Fig. 3.4. Block of the proposed adaptive antenna array system

Here, we use the N elements antenna array. Then it is converted into a steering vector and correlation matrix. Then each element is multiplied by the weight. Finally, we got an output. This output signal is compared with the desired signal to find an error. Error is multiplied by the algorithm which we used. It is used as the next weight and we got the next output signal.

CHAPTER 4

PERFORMANCE ANALYSIS

4.1. Introduction

We compare these techniques with a number of criteria to obtain the performance of four adaptive techniques. We analysis power patterns for LMS, ALMS, RLS, and CG. The analysis of the convergence between these methods is our main comparison. We introduce error analysis and weight stability to demonstrate the convergence analysis.

4.2. Performance Analysis

Convergence means how quickly the actual signal matches or converges with the desired response in terms of array analysis. We tested four adaptive strategies in our study to see which technique is conveying faster. To cross-check our convergence analysis, error analysis and weight stability graph are also provided on this page. The analysis is done for the linear array.

To check the convergence rate for linear arrays, we compare the adaptive array output with the desired response. As with the general case, the optimal answer is assumed to be a cosine curve. It samples 70 times each of the actual output and desired signal. All weights are considered to be zero. For our analysis, we used a linear array of 8 elements.

4.2.1. Power Pattern Analysis

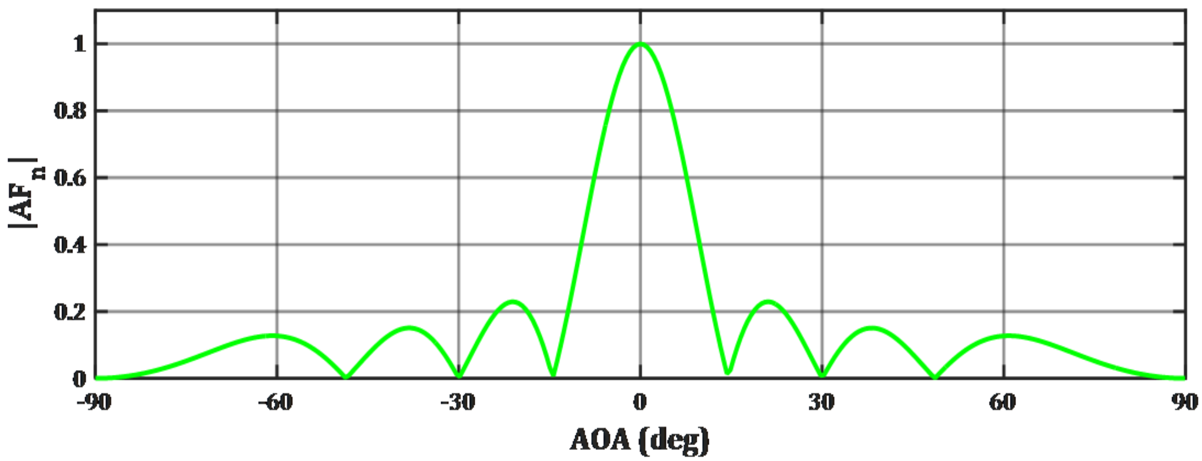


Fig.4.1. Power pattern Analysis of LMS.

Fig 4.1. shows the power pattern of the LMS algorithm. It has a wide main beam. The main beam is steered at 0 degrees. Side Lobe Level varies from -90 degrees – 90 degrees. It has a low side lobe.

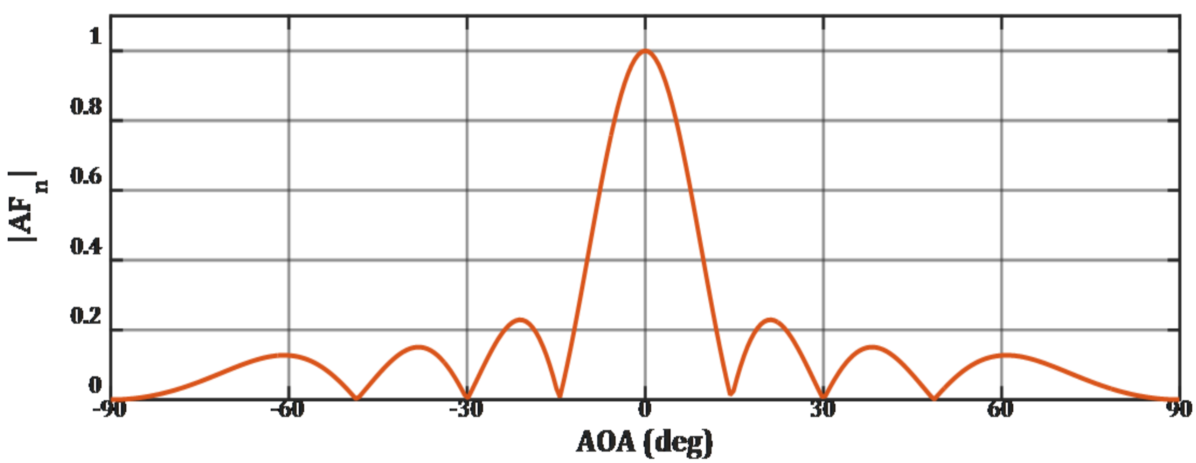


Fig.4.2. Power pattern Analysis of ALMS.

Fig 4.2. shows the power pattern of the ALMS algorithm. It has a wide main beam. The main beam is steered at 0 degrees. Side Lobe Level varies from -90 degrees – 90 degrees. It has low sidelobe as same as LMS.

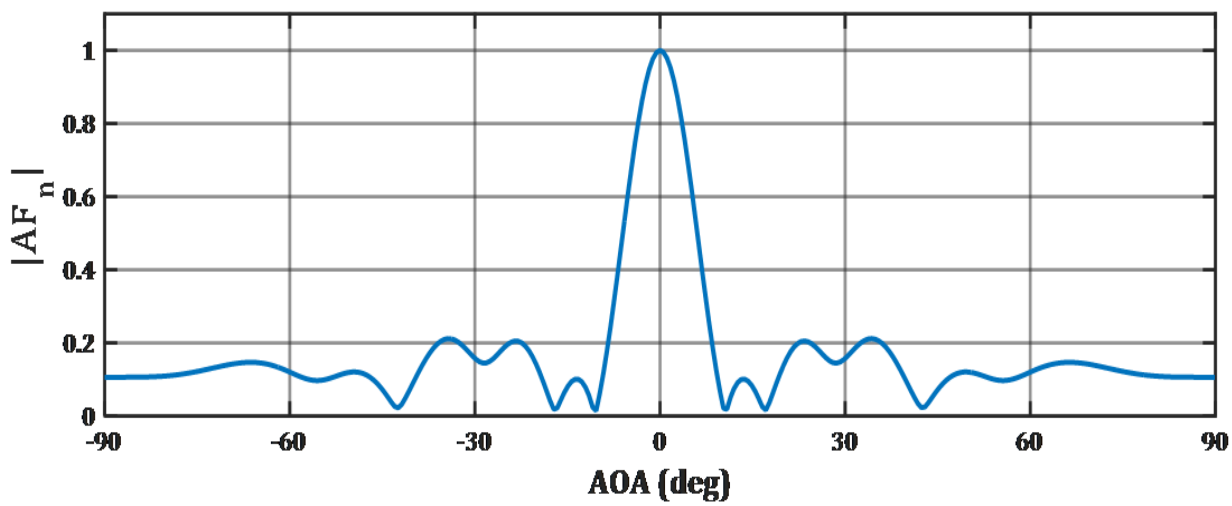


Fig.4.3. Power pattern Analysis of RLS.

Fig 4.3. shows the power pattern of the RLS algorithm. It has a wide main beam. The main beam is steered at 0 degrees. Side Lobe Level varies from -90 degrees – 90 degrees. Its side lobe level is higher than LMS and ALMS.

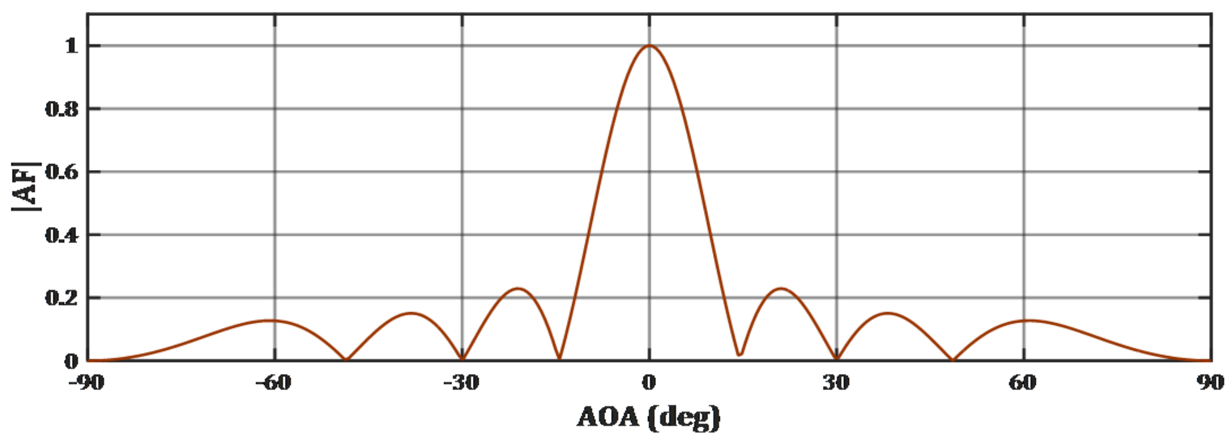


Fig.4.4. Power pattern Analysis of CG.

Fig 4.4. shows the power pattern of the CG algorithm. It has a wide main beam. The main beam is steered at 0 degrees. Side Lobe Level varies from -90 degrees – 90 degrees. It has a low sidelobe level.

4.2.2. Converging Analysis

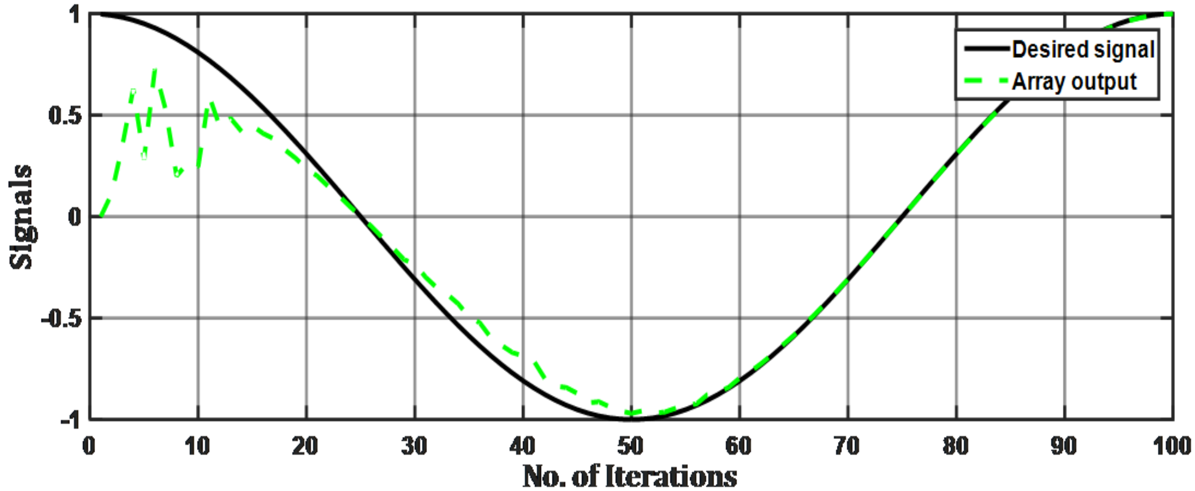


Fig.4.5. Convergence analysis for LMS algorithms

LMS converges more quickly than RLS but slowly than ALMS and CG. In Fig.3.5. It converges at 63rd iterations.

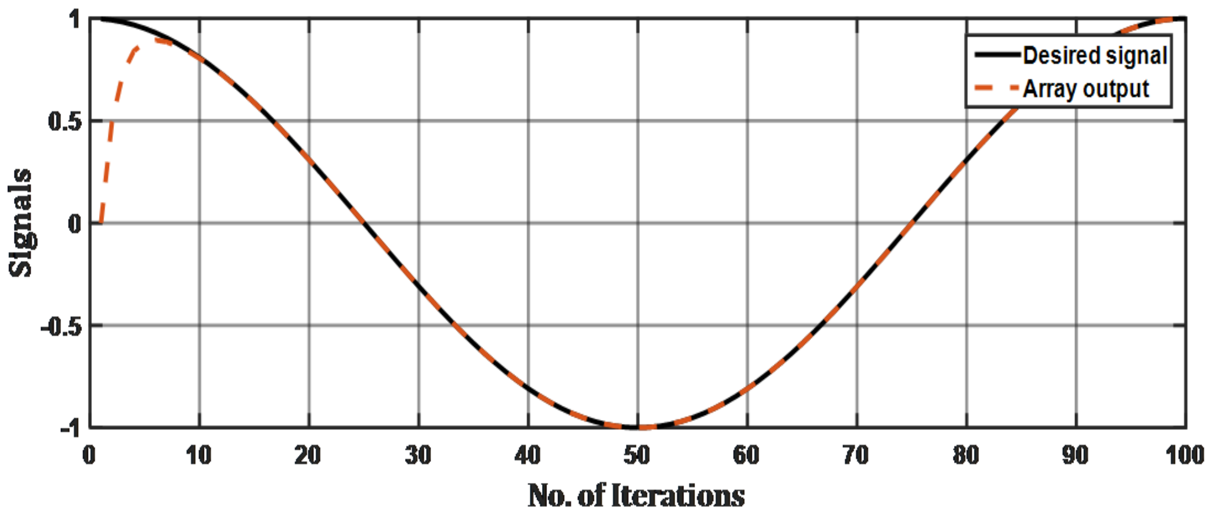


Fig. 4.6. Convergence analysis for ALMS algorithms

ALMS converges faster than any other algorithm (RLS, LMS &CG). In Fig.3.6. It converges at 9th iterations.

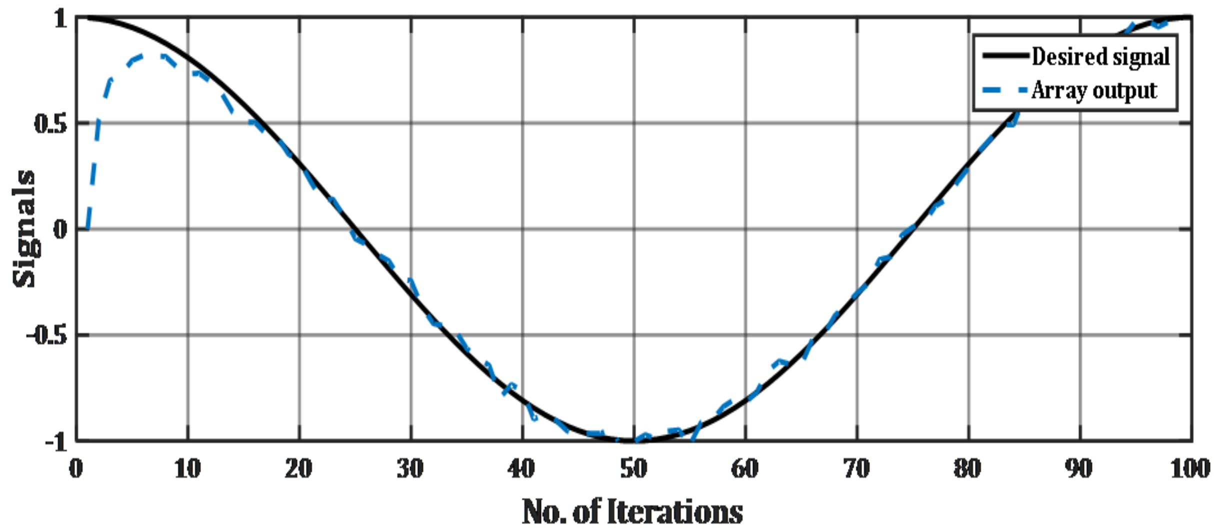


Fig. 4.7. Convergence analysis for RLS algorithms

In our observation, RLS is the slowest algorithm technique. It is not completely converged in 100 iterations.

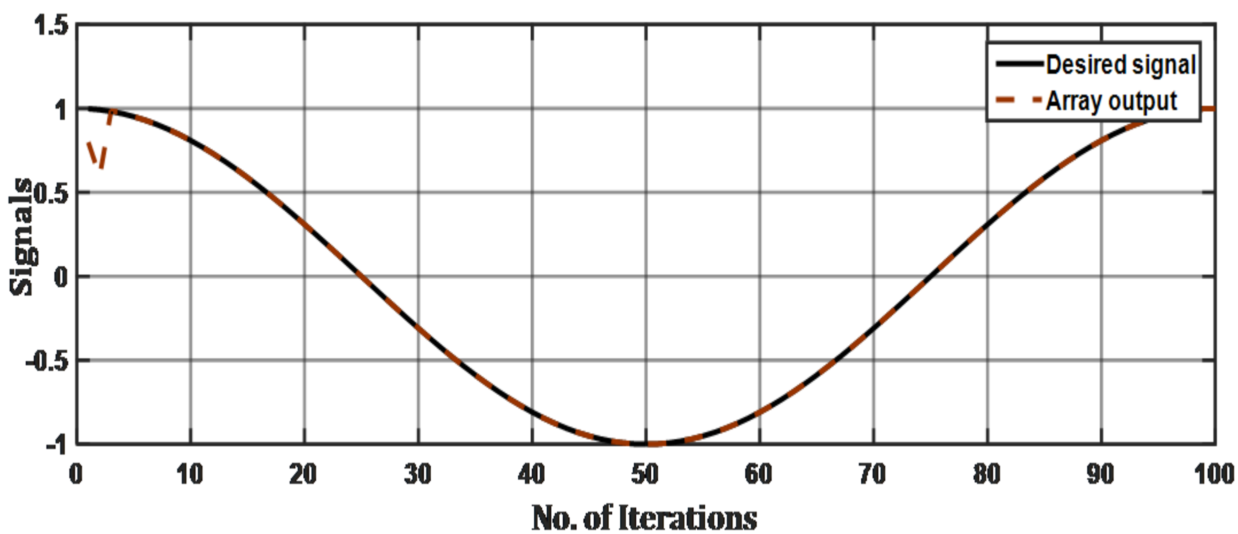


Fig. 4.8. Convergence analysis for CG algorithms

Conjugate Gradient Algorithm is faster than RLS and LMS. It converges at 21st iteration.

4.2.3. Error Analysis

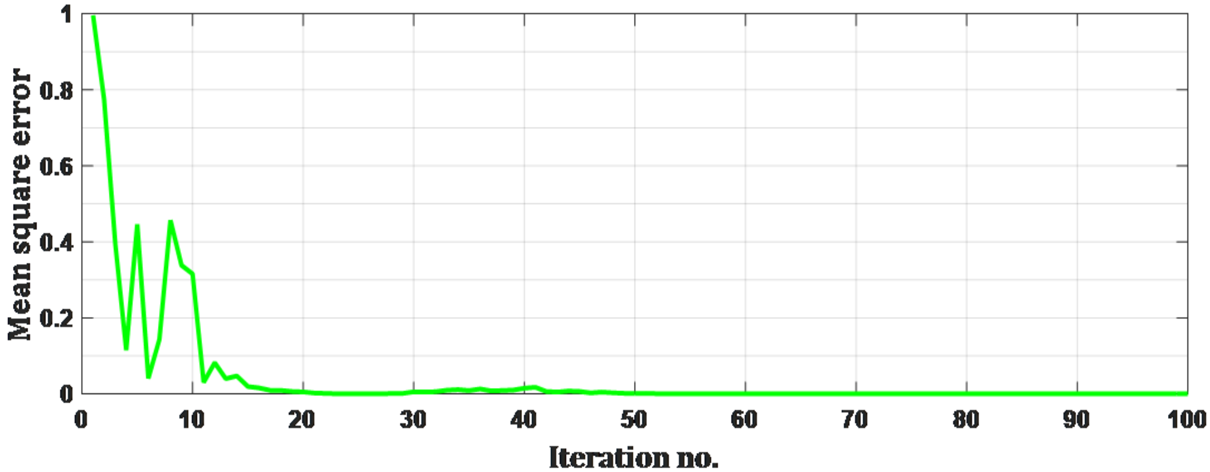


Fig. 4.9. Error analysis for LMS algorithms

In **Fig. 3.9.** error for LMS becomes zero at 63rd iterations.

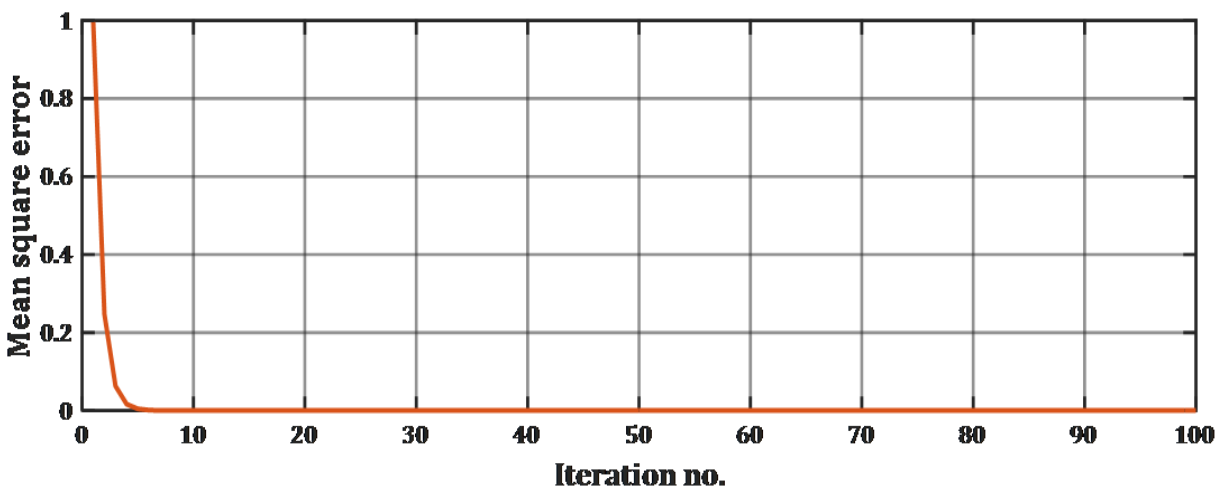


Fig. 4.10. Error analysis for ALMS algorithms

In **Fig. 3.10.** Error for ALMS becomes zero at 9th iterations.

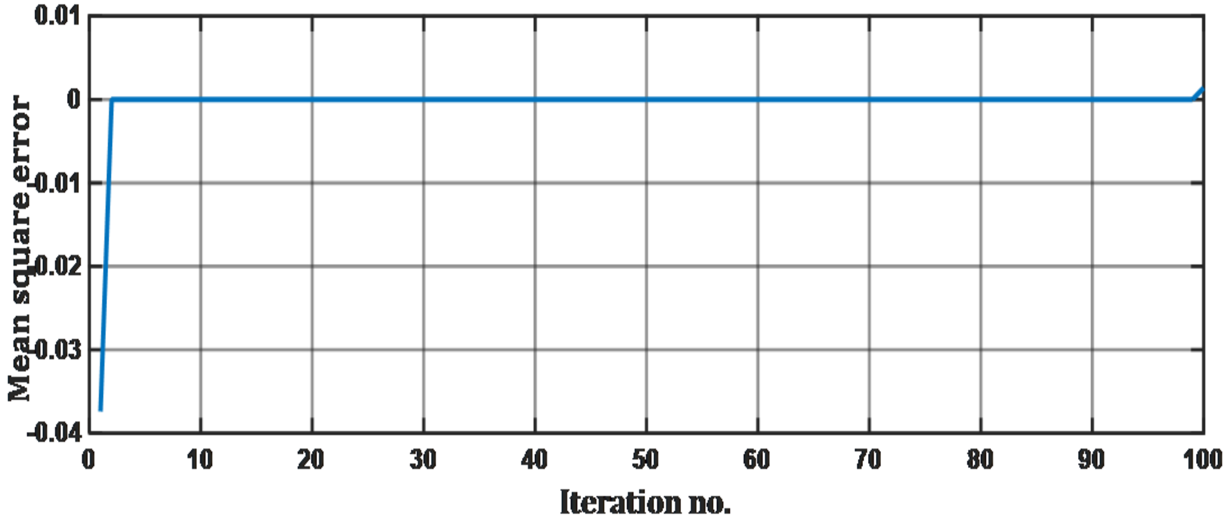


Fig. 4.11. Error analysis for RLS algorithms

In **Fig. 3.11.** Error for RLS is not completely converged in the number of 100^{th} iteration.

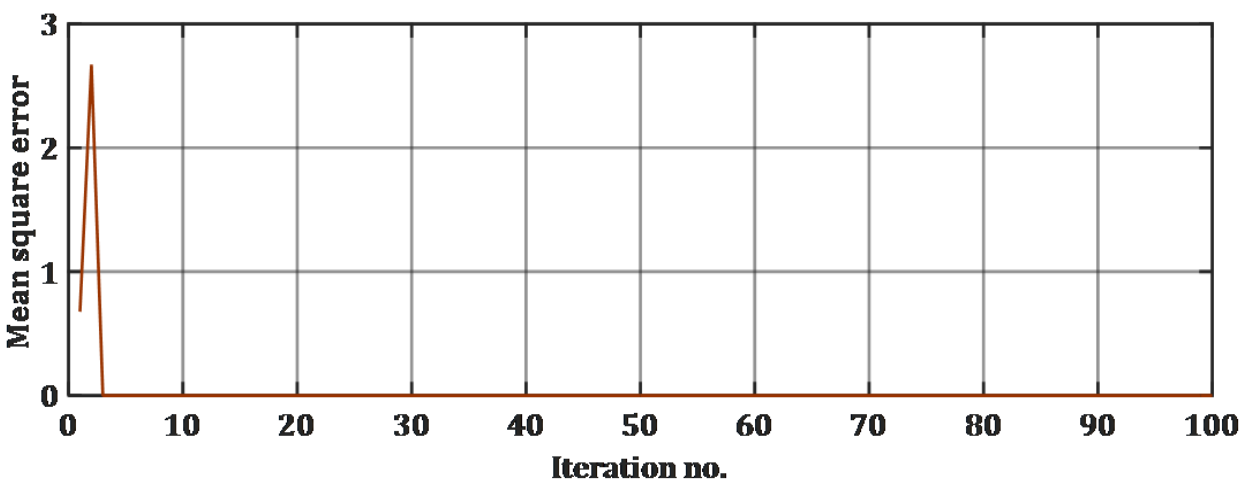


Fig. 4.12. Error analysis for CG algorithms

In **Fig. 3.12.** Error for ALMS becomes zero at 21st iterations.

In **Fig. 3.9. Fig. 3.10. Fig. 3.11. And Fig. 3.12.** adaptive algorithms are checked for their weight stability.

4.2.4. Weight Analysis

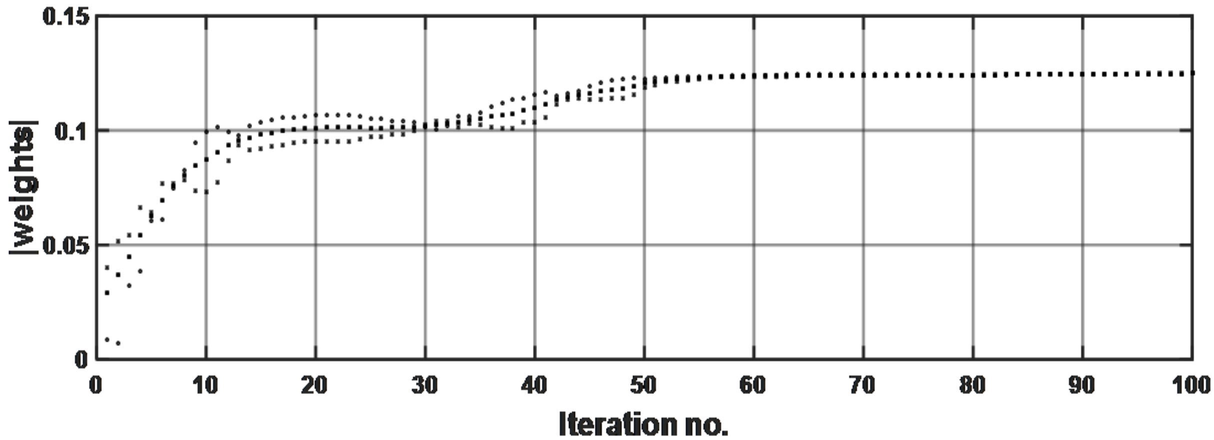


Fig. 4.13. Weight stability for LMS algorithms

In Fig.4.13. LMS algorithms are checked for weight stability. LMS weight becomes stable from 60th iterations.

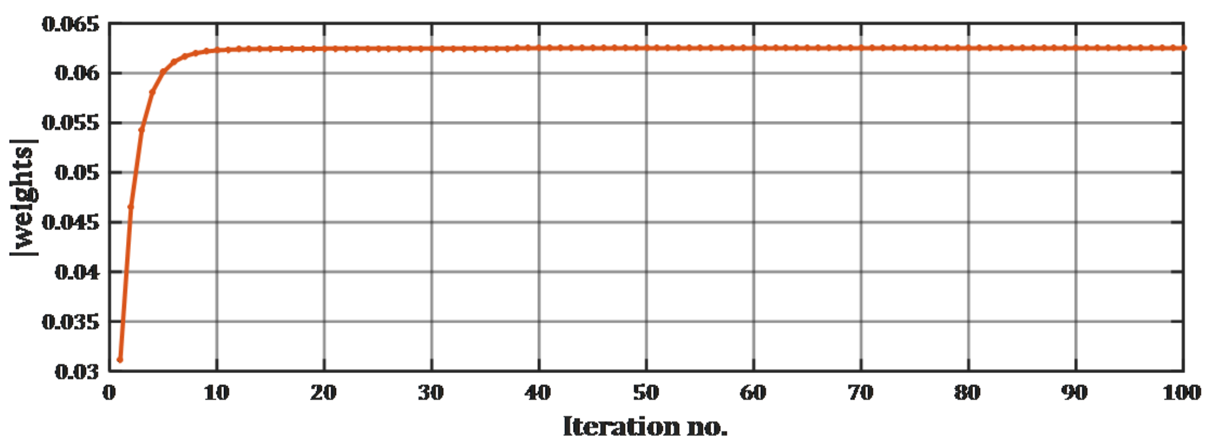


Fig. 4.14. Weight stability for ALMS algorithms

In Fig.4.14. ALMS algorithms are checked for weight stability. ALMS weight becomes stable from 9th iterations.

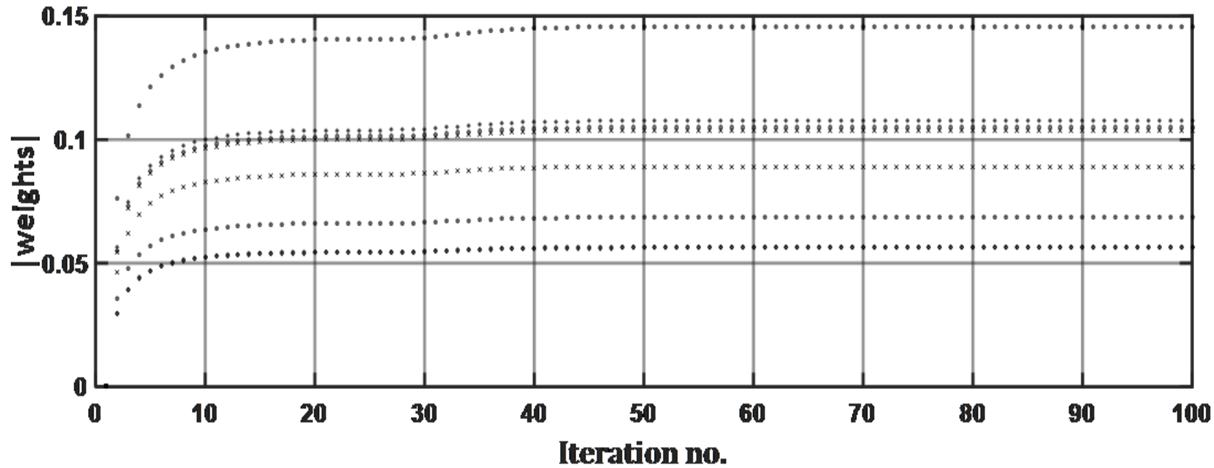


Fig. 4.15. Weight stability for RLS algorithm

In Fig.4.15. RLS algorithms are checked for weight stability. RLS weight becomes stable from 50th iterations.

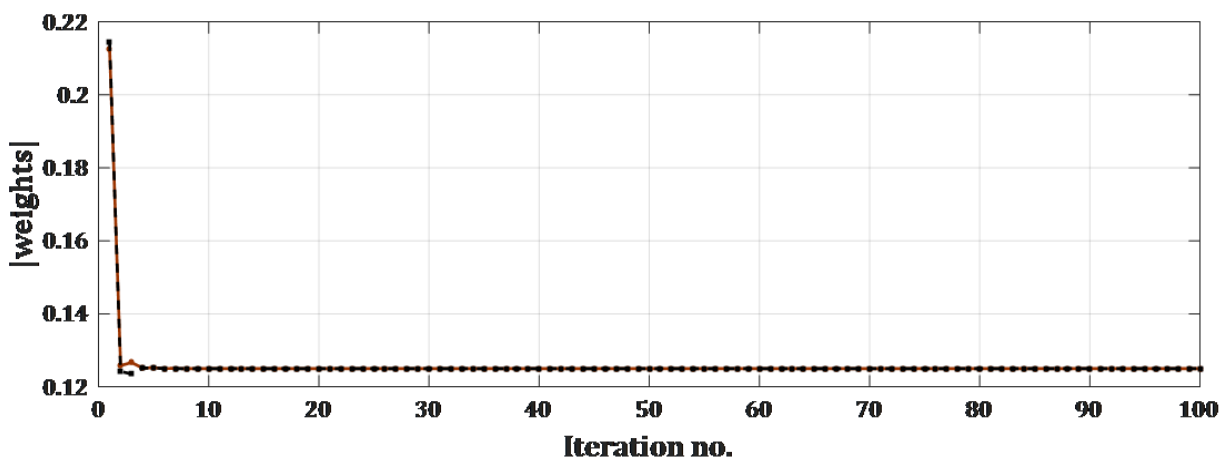


Fig. 4.16. Weight stability for CG algorithm

In Fig.4.15. RLS algorithms are checked for weight stability. RLS weight becomes stable from 12th iterations.

4.2.5. Error Analysis From Matlab

```
Columns 43 through 49

  0.0055    0.0010    0.0105    0.0006    0.0071    0.0022    0.0019

Columns 50 through 56

  0.0020    0.0010    0.0007    0.0004    0.0002    0.0006    0.0002

Columns 57 through 63

  0.0002    0.0001    0.0001    0.0001    0.0001    0.0001    0.0000

Columns 64 through 70

  0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
```

Fig. 4.17. Error analysis of LMS algorithm from Matlab data

In fig 4.17. the error for LMS becomes zero in 63rd iterations.

```
Columns 1 through 7

  0.9961    0.2480    0.0627    0.0163    0.0044    0.0013    0.0004

Columns 8 through 14

  0.0001    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000

Columns 15 through 21

  0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000

Columns 22 through 28

  0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000
```

Fig. 4.18. Error analysis of ALMS algorithm from Matlab data

In fig 4.18. the error for ALMS becomes zero at 9th iterations.

```
Columns 78 through 84

       0         0         0         0         0         0         0

Columns 85 through 91

       0         0         0         0         0         0         0

Columns 92 through 98

       0         0         0         0         0         0         0

Columns 99 through 100

       0    0.0002
```

Fig. 4.19. Error analysis of RLS algorithm from Matlab data

In fig 4.19. the error for RLS is zero between 2 iterations to 99 iterations. But at 100th iteration, there is a value of error. So we can say the error for RLS is not completely zero in 100th iterations.

```
Columns 17 through 20

-0.0001 - 0.0003i  -0.0001 - 0.0006i   0.0000 + 0.0001i   0.0000 + 0.0001i

Columns 21 through 24

 0.0000 + 0.0000i   0.0000 + 0.0000i   0.0000 + 0.0000i   0.0000 + 0.0000i

Columns 25 through 28

-0.0000 - 0.0000i  -0.0000 - 0.0000i   0.0000 + 0.0000i   0.0000 + 0.0000i

Columns 29 through 32

-0.0000 - 0.0000i   0.0000 + 0.0000i   0.0000 + 0.0000i   0.0000 + 0.0000i
```

Fig. 4.20. Error analysis of CG algorithm from Matlab data

In fig.4.20. the error for CG becomes zero from 21st iteration to 100th iterations.

4.3.Comparison among different Adaptive Algorithm

Table-1. Comparison among different algorithms.

Adaptive Algorithm	Convergence Rate (No. of iteration)	Error Becomes zero (No. of iteration)	Weight Stability (No. of iteration)
LMS	**63**	**63**	**60**
ALMS	**9**	**9**	**9**
RLS	Do not converge at 100 iteration	Do not converge at 100 iteration	**50**
CG	**21**	**21**	**12**

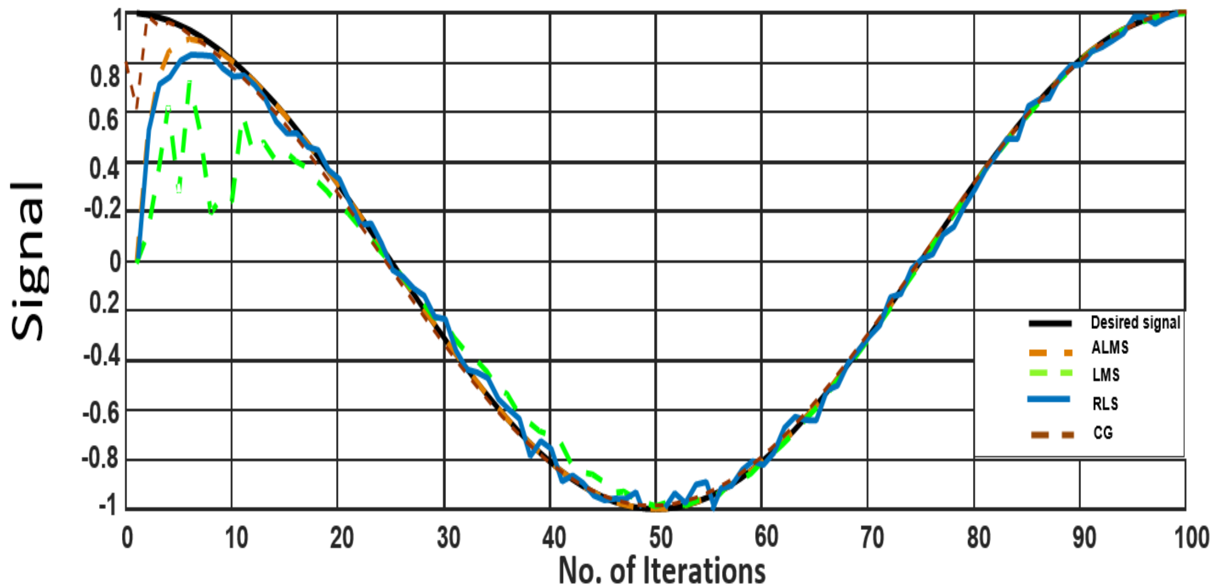


Fig.4.21. Convergence analysis for adaptive algorithms

In fig.4.17. we see that ALMS converges more quickly than LMS, RLS, and CG. ALMS converge at only 9th iterations whereas, LMS converge at 63rd iterations, RLS is not converged in 100th iterations and CG converge at 21st iterations. Finally, we can say that ALMS is faster than LMS, RLS, and CG.

CHAPTER 5

RESULT AND FUTURE WORK

5.1. Conclusion

In this thesis, the most convergent approach for linear arrays was used in various adaptive techniques. LMS, ALMS, CG, and RLS are the adaptive techniques used in a linear array. After all, simulation augmented least mean square (ALMS) adaptive algorithm showed the best convergence with the desired signal. ALMS algorithm has converged at 9th iteration. We also presented a mean square error analysis and weight stability analysis to further verify our convergence analysis. The two analyzes both show that ALMS is the faster way. This algorithm provides a low side lobe. In this algorithm, the error becomes zero faster than any algorithm. The weight is also stable more quickly than LMS, RLS & CG. There is much application of the fastest algorithms like Satellite communication, Terrestrial communication, RADAR, SONAR, Hydrology, Climatography, Ecology, etc. There is a requirement in radar to fastest object detection which depends on the fastest converging method. If the converging method is fast we will detect the object as fast as possible.

5.2. Future work

In this thesis, the adaptive technique is applied. There is no shortage of applications in which optimization of the array geometry is beneficial. Obviously, for future work and changes, a lot of possibilities and variety remains. There are some future areas below,

- The adaptive techniques can be applied for uniform planar array and concentric circular array.
- The adaptive techniques can be applied for uniform planar array and concentric circular array.
- Interference cancellation can be kept on further consideration.
- The robust technique can be applied.
- Method to obtain better stability can be a further research consideration.
- The advanced array synthesizing techniques can be applied and compared in further studies.

REFERENCES

[1] C. A. Balanis, "Antenna theory: Analysis and Design", 3rd edition, A John Wiley & Sons, 2005.

[2] D. K. Cheng, "Field and Wave Electromagnetics" , 2nd edition, Pearson, 2004.

[3] L.Gargouri[1], R.Ghayoula[1], N.Fadlallah[2], A.Gharsallah[1], M.Rammal [2] "
Steering an Adaptive Antenna Array by LMS Algorithm"-2009

[4] Jalal Abdulsayed Srar, Kah-Seng Chung, and Ali Mansour, "Adaptive Array Beamforming Using a Combined LMS-LMS Algorithm", TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 58, NO. 11, NOVEMBER 2010.

[5] S. Das, M. Bhattacharya, A. Sen, and D. Mandal, "Linear antenna array synthesis with decreasing sidelobe and narrow beam-width", ACEEE International Journal on Communications, 3(1), 2012, pp. 10-14.

[6] J. D. Essiben, P. M. Zanga, E. R. Hedin and Y. S. Joe, "Design of Non-Uniform Linear Antenna Arrays Using Dolph-Chebyshev and Binomial Methods", International Journal of Engineering Research and Applications, Vol. 5, Issue 8, (Part - 5), pp.187-195, August 2015.

[7] L. C. Godara, "Applications of Antenna Arrays to Mobile Communications. I. Performance improvement, feasibility, and system considerations", Proceedings of the IEEE, vol. 85, pp. 1031-1060, 1997.

[8] B. D. Van Veen and K. M. Buckley, "Beamforming: A Versatile Approach to Spatial Filtering", IEEE Acoustics Speech and Signal Processing Magazine, Vol. 5, pp. 4-24, 1988.

[9] Y. Zou, Z. L. Yu, and Z. Lin, "A robust algorithm for linearly constrained adaptive beamforming", IEEE Signal Processing Letters, vol. 11, pp. 26-29, Jan. 2004.

[10] C. Farsakh and J. A. Nossek, "Spatial covariance based downlink beamforming in an SDMA mobile radio system," IEEE Trans. Commun., vol. 46, pp. 1497-1506, November 1998.

[11] D. G. Manolakis, V. K. Ingle, and S. M. Kogon, "Statistical and Adaptive Signal Processing", 2nd edition, McGraw-Hill, 2005.

[12] J. Boccuzzi, "Signal Processing for Wireless Communications", 2nd edition, McGraw-Hill, 2007.

[13] Panayiotis Ioannides and Constantine A. Balanis, "Uniform Circular and Rectangular Arrays for Adaptive Beamforming Applications," ANTENNAS AND WIRELESS PROPAGATION LETTERS, VOL. 4, 2005

[14] D. H. Johnson, D. E. Dudgeon, "Array Signal Processing", 1st edition, Prentice Hall, 1993.

[15] Smita Banerjee and Ved Vyas Dwivedi, "Performance Analysis of Adaptive Beamforming using Particle Swarm Optimization", 11th International Conference on Industrial and Information Systems (ICIIS), 3-4 Dec. 2016.

[16] Vijendra Mishral, Gaurav Chaitanya[2] , “Analysis of LMS, RLS and SMI Algorithm on the Basis of Physical Parameters for Smart Antenna”, Conference on IT in Business, Industry and Government (CSIBIG) -2014.

[17] L. C. Godara, “Smart Antennas”, New York: CRC Press, 2004.

[18] Raafia Irfan1 , Haroon ur Rasheed1, Waqas A Toor2, Muhammad Ashraf[2], “Performance analysis of adaptive algorithms for space-time adaptive processor (STAP) in phased array radar”, - IET International Radar Conference (IRC 2018).

[19] Jianxin Wu, Tong Wang, and Zheng Bao, “Fast Realization of Maximum Likelihood Angle Estimation With Small Adaptive Uniform Linear Array”, TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 58, NO. 12, DECEMBER 2010.

[20] J. Okkonen, “Uniform Linear Adaptive Antenna Array Beamforming Implementation with a Wireless Open-access Research Platform.” University of Oulu, Department of Computer Science and Engineering, Master’s Thesis, 58 p, 2013.

[21] C. L. Dolph, “A Current Distribution for Broadside Arrays which Optimizes the Relationship between Beamwidth and Side Lobe Level”, Proc. IRE and Waves and Electrons, June 1946.

[22] T. T. Tylor, “Design of Line Source Antenna for Narrow Beamwidth and Low Side Lobes”, IRE Transaction on Antennas Propagation, Vol. AP-3, No.1, pp. 16-28. January 1955.

[23] B. WIDROW, P. E. MANTEY, MEMBER, L. J. GRIFFITHS, AND B. B. GOODE, “Adaptive Antenna Systems”,- VOL. 55, NO. 12, DECEMBER 1967

[24] G. Ungerboeck, “Theory on the speed of convergence in adaptive equalizers for digital com- munication,” IBM Journal on Research and Development, vol. 16, pp. 546-555, November, 1972.

[25] O. L. Frost, “An algortihm for linearly constrained adaptive array processing”, IEEE Proceedings, pp. 27-34, 1972.

[26] A. T. Abed, “Improving Directivity and SLL max in Uniform Space and Non-Uniform Excitation Antenna Arrays”, Canadian Journal on Electrical and Electronics Engineering, Vol. 3, No. 8, pp. 452-457, October 2012.

[27] L.Gargouri[1], R.Ghayoula[1], N.Fadlallah[2], A.Gharsallah[1], M.Rammal[2], “ Steering an Adaptive Antenna Array by LMS Algorithm”,-2009.

[28] Jianxin Wu, Tong Wang, and Zheng Bao, “Fast Realization of Maximum Likelihood Angle Estimation With Small Adaptive Uniform Linear Array”,- VOL. 58, NO. 12, DECEMBER 2010

[29] S. Haykin and T. Kailath, “Adaptive Filter Theory”, 4th edition, Pearson Education, 2009.

[30] E. Zeraatkar*, M. Soltani*, P. Karimaghaee, “A fast convergence algorithm for BPNN based on Optimal Control Theory Based Learning Rate”,-2011.

[31] Mrityunjoy Chakraborty, Senior Member, IEEE, and Hideaki Sakai, Senior Member, IEEE, “Convergence Analysis of a Complex LMS Algorithm With Tonal Reference Signals,”- VOL. 13, NO. 2, MARCH 2005.

[32] E. Zeraatkar*, M. Soltani*, P. Karimaghaee* “A fast convergence algorithm for BPNN based on Optimal Control Theory Based Learning Rate”, 2011 2nd International Conference on Control, Instrumentation and Automation

[33] Prakash, Jong-gil Baek, Hyeji Jeon, Hyejin Lee, Min A Jeong and Seong Ro Lee, “Performances of RLS Algorithm for Smart Antennas in Mobile Communication System”,-2015.

[34] Raafia Irfan1 , Haroon ur Rasheed1, Waqas A Toor2, Muhammad Ashraf, “Performance analysis of adaptive algorithms for space-time adaptive processor (STAP) in phased array radar”, IET International Radar Conference (IRC 2018)

[35] Jalal Abdulsayed Srar and Kah-Seng Chung, “Performance of RLMS Algorithm in Adaptive Array Beam Forming”, 11th IEEE Singapore International Conference on Communication Systems -2008.