SMART ANTENNAS AND BEAMFORMING FOR WIRELESS COMMUNICATION

Project Report submitted in partial fulfillment of the
requirement for the degree of

Bachelor of Technology

in

Electronics and Communication Engineering

By

Aditi Joshi (061010)

Devanshu (061045)

Mayank Agarwal (061071)

under the Supervision of

Dr. Pradeep Kumar

Jaypee University of Information Technology

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Certificate

This is to certify that the project report entitled "SMART ANTENNAS AND BEAMFORMING FOR WIRELESS COMMUNICATION", submitted by Aditi Joshi (061010), Devanshu (061045), Mayank Agarwal (061071) in partial fulfillment for the award of degree of Bachelor of Technology in Electronics and Communication Engineering to Jaypee University of Information Technology, Waknaghat, Solan has been carried out under my supervision.

Date : 15.05.10

Signature
Dr. Pradeep Kumar
(Asst. Professor)

Certified that this work has not been submitted partially or fully to any other University or Institute for the award of this or any other degree or diploma

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Acknowledgement

Apart from the efforts of team members, the success of this project depends largely on the encouragement and guidance of many others. We take this opportunity to express our gratitude to the people who have been instrumental in the successful completion of this project.

We would like to show our greatest appreciation to Dr. Pradeep Kumar. We can't thank him enough for his tremendous support and help. Without his encouragement and guidance this project would not have materialized.

The guidance and support received from all the team members who contributed and are contributing to this project, was vital for the success of the project. We are grateful for their constant support and help.

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Abstract

The subject of smart antennas is beginning to enjoy immense popularity due to the current exponential growth in all forms of wireless communications and sensing. This project has been undertaken in response to the recent extreme interest in the rapidly growing field of smart antennas. Although some of the principles of smart antennas have been around for over forty years, new wireless applications demanding smart antenna technology are growing exponentially.

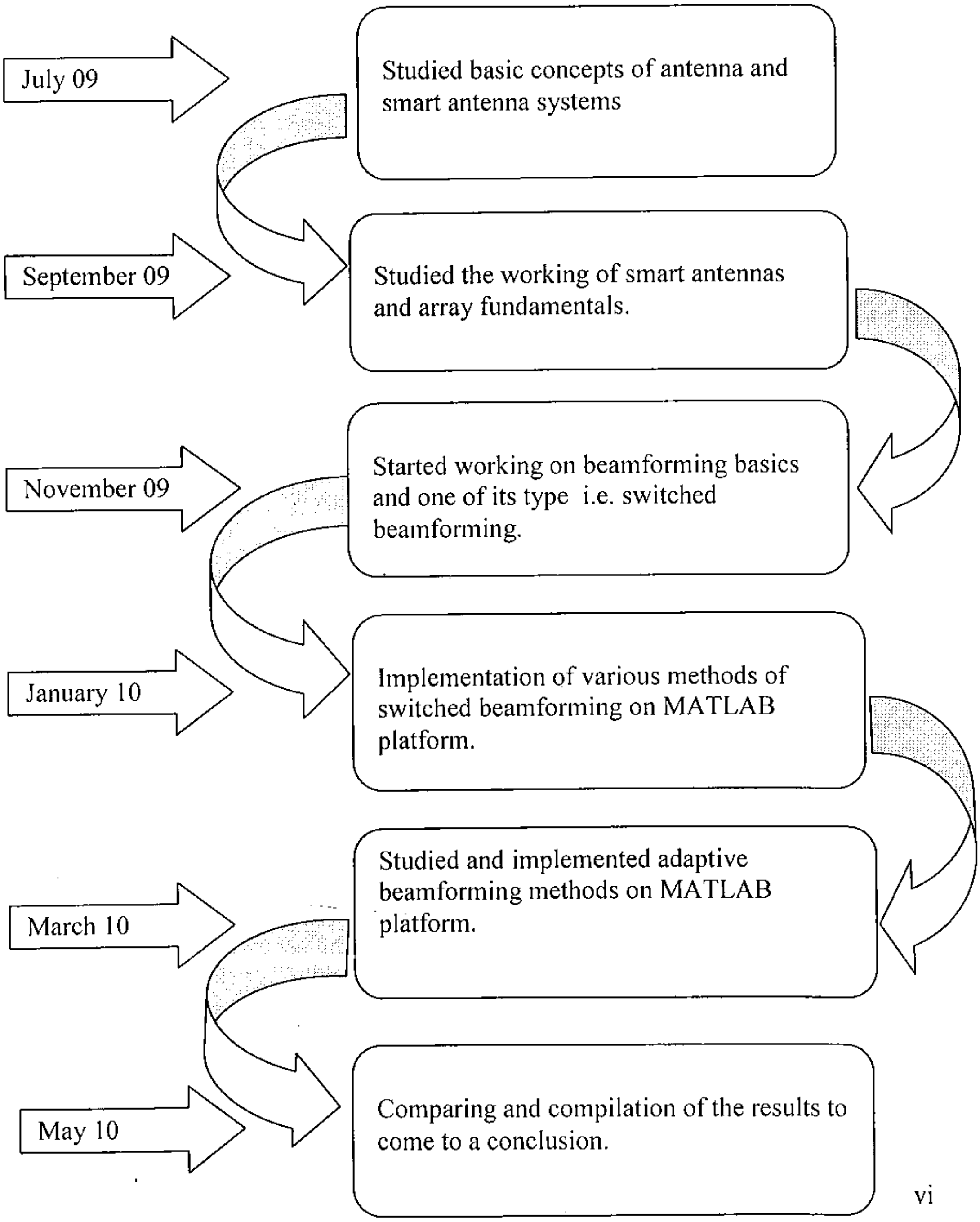
The term "smart antenna" generally refers to any antenna array, terminated in a sophisticated signal processor, which can adjust or adapt its own beam pattern in order to emphasize signals of interest and to minimize interfering signals.

The project encompasses both switched beam and adaptive beamforming systems. Switched beam systems have several available fixed beam patterns. A decision is made as to which beam to access, at any given point in time, based upon the requirements of the system. Beamformed adaptive systems allow the antenna to steer the beam to any direction of interest while simultaneously nulling interfering signals.

Smart antenna patterns are controlled via algorithms based upon certain criteria. These criteria could be maximizing the signal-to-interference ratio (SIR), minimizing the variance, minimizing the meansquare error (MSE), steering toward a signal of interest, nulling the interfering signals, or tracking a moving emitter to name a few. The project implements some of these algorithms and compares the result.

Project Progress

The following is our project progress:



July 09

Studied basic concepts of antenna and smart antenna systems

September 09

Studied the working of smart antennas and array fundamentals.

November 09

Started working on beamforming basics and one of its type i.e. switched beamforming.

January 10

Implementation of various methods of switched beamforming on MATLAB platform.

March 10

Studied and implemented adaptive beamforming methods on MATLAB platform.

May 10

Comparing and compilation of the results to come to a conclusion.

CHAPTER 1

1. INTRODUCTION

Almost everyone uses at least one antenna each day. In fact, the majority of people use antennas for many conveniences in their daily life, whether they realize it or not. Devices such as keyless entry systems, freeway toll passes, satellite TV systems, pagers, cell phones, and wireless networks all require antennas. Very few people who use these antennas can explain how and why they work.

1.1 Antennas

An antenna (or aerial) is a transducer designed to transmit or receive electromagnetic waves. In other words, antennas convert electromagnetic radiation into electrical current, or vice versa. Antennas generally deal in the transmission and reception of radio waves, and are a necessary part of all radio equipment. Antennas are used in systems such as radio and television broadcasting, point-to-point radio communication, wireless LAN, cell phones, radar, and spacecraft communication. Antennas are most commonly employed in air or outer space, but can also be operated under water or even through soil and rock at certain frequencies for short distances.

Physically, an antenna is an arrangement of one or more conductors, usually called elements. In transmission, an alternating current is created in the elements by applying a voltage at the antenna terminals, causing the elements to radiate an electromagnetic field. In reception, the inverse occurs: an electromagnetic field from another source induces an alternating current in the elements and a corresponding voltage at the antenna's terminals.

1.2 Parameters

Here are several critical parameters affecting an antenna's performance that can be adjusted during the design process. These are resonant frequency, impedance, gain, aperture or radiation pattern. Transmit antennas may also have a maximum power rating, and receive antennas differ in their noise rejection properties. All of these parameters can be measured through various means.

1.2.1 Resonant frequency

The "resonant frequency" and "electrical resonance" is related to the electrical length of an antenna. The electrical length is usually the physical length of the wire divided by its velocity factor (the ratio of the speed of wave propagation in the wire to c, the speed of light in a vacuum). Typically an antenna is tuned for a specific frequency, and is effective for a range of frequencies that are usually centered on that resonant frequency. However, other properties of an antenna change with frequency, in particular the radiation pattern and impedance, so the antenna's resonant frequency may merely be close to the center frequency of these other more important properties.

Antennas can be made resonant on harmonic frequencies with lengths that are fractions of the target wavelength; this resonance gives much better coupling to the electromagnetic wave, and makes the aerial act as if it were physically larger.

Some antenna designs have multiple resonant frequencies, and some are relatively effective over a very broad range of frequencies. The most commonly known type of wide band aerial is the logarithmic or log periodic, but its gain is usually much lower than that of a specific or narrower band aerial.

1.2.2 Gain

Gain as a parameter measures the efficiency of a given antenna with respect to a given norm, usually achieved by modification of its directionality. An antenna with a low gain emits radiation with about the same power in all directions, whereas a high-gain antenna will preferentially radiate in particular directions. Specifically, the **Gain**, **Directive gain** or **Power gain** of an antenna is defined as the ratio of the intensity (power per unit surface) radiated by the antenna in a given direction at an arbitrary distance divided by the intensity radiated at the same distance by a hypothetical isotropic antenna.

The gain of an antenna is a passive phenomenon - power is not added by the antenna, but simply redistributed to provide more radiated power in a certain direction than would be transmitted by an isotropic antenna. If an antenna has a gain greater than one in some directions, it must have a gain less than one in other directions, since energy is conserved by the antenna. An antenna designer must take into account the application for the antenna when determining the gain. High-gain antennas have the advantage of longer range and better signal quality, but must be aimed carefully in a particular direction. Low-gain antennas have shorter range, but the orientation of the antenna is relatively inconsequential. For example, a dish antenna on a spacecraft is a high-gain device that must be pointed at the planet to be effective, whereas a typical Wi-Fi antenna in a laptop computer is low-gain, and as long as the base station is within range, the antenna can be in any orientation in space.

1.2.3 Radiation pattern

Fig 1.1 Radiation Pattern of an antenna

The radiation pattern of an antenna is the geometric pattern of the relative field strengths of the field emitted by the antenna. For the ideal isotropic antenna, this would be a sphere. For a typical dipole, this would be a toroid. The radiation pattern of an antenna is typically represented by a three dimensional graph, or polar plots of the horizontal and vertical cross sections. The graph should show sidelobes and backlobes, where the antenna's gain is at a minima or maxima.

1.2.4 Impedance

As an electro-magnetic wave travels through the different parts of the antenna system (radio, feed line, antenna, free space) it may encounter differences in impedance (E/H, V/I, etc.). At each interface, depending on the impedance match, some fraction of the wave's energy will reflect back to the source, forming a standing wave in the feed line. The ratio of maximum power to minimum power in the wave can be measured and is called the standing wave ratio (SWR). A SWR of 1:1 is ideal. A SWR of 1.5:1 is considered to be marginally acceptable in low power applications where power loss is more critical, although an SWR as high as 6:1 may still be usable with the right equipment. Minimizing impedance differences at each interface (impedance matching) will reduce SWR and maximize power transfer through each part of the antenna system.

Complex impedance of an antenna is related to the electrical length of the antenna at the wavelength in use. The impedance of an antenna can be matched to the feed line and radio by adjusting the impedance of the feed line, using the feed line as an impedance transformer.

1.2.5 Efficiency

Efficiency is the ratio of power actually radiated to the power put into the antenna terminals. A dummy load may have an SWR of 1:1 but an efficiency of 0, as it absorbs all power and radiates heat but not RF energy, showing that SWR alone is not an effective measure of an antenna's efficiency. Radiation in an antenna is caused by radiation resistance which can only be measured as part of total resistance including loss resistance. Loss resistance usually results in heat generation rather than radiation, and reduces efficiency. Mathematically, efficiency is calculated as radiation resistance divided by total resistance.

1.2.6 Bandwidth

The bandwidth of an antenna is the range of frequencies over which it is effective, usually centered on the resonant frequency. The bandwidth of an antenna may be increased by several techniques, including using thicker wires, replacing wires with cages to simulate a thicker wire, tapering antenna components (like in a feed horn), and combining multiple antennas into a single assembly and allowing the natural impedance to select the correct antenna. Small antennas are usually preferred for convenience, but there is a fundamental limit relating bandwidth, size and efficiency.

1.3 Types of Antennas

1.3.1 Omnidirectional Antennas

Since the early days of wireless communications, there has been the simple dipole antenna, which radiates and receives equally well in all directions. To find its users, this single-element design broadcasts omnidirectionally in a pattern resembling ripples radiating outward in a pool of water. While adequate for simple RF environments where no specific knowledge of the users' whereabouts is available, this unfocused approach scatters signals, reaching desired users with only a small percentage of the overall energy sent out into the environment.

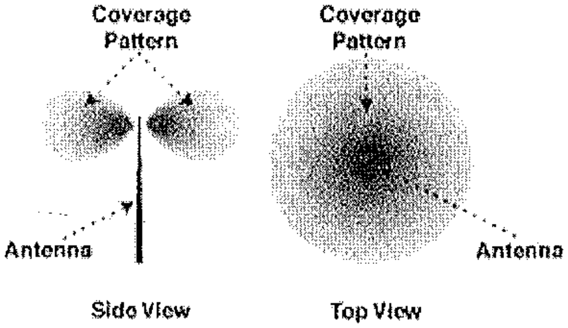


Fig 1.2 Omnidirectional Antenna and Coverage Patterns

Given this limitation, omnidirectional strategies attempt to overcome environmental challenges by simply boosting the power level of the signals broadcast. In a setting of numerous users (and interferers), this makes a bad situation worse in that the signals that miss the intended user become interference for those in the same or adjoining cells.

In uplink applications (user to base station), omnidirectional antennas offer no preferential gain for the signals of served users. In other words, users have to shout over competing signal energy. Also, this single-element approach cannot selectively reject signals interfering with those of served users and has no spatial multipath mitigation or equalization capabilities.

Omnidirectional strategies directly and adversely impact spectral efficiency, limiting frequency reuse. These limitations force system designers and network planners to devise increasingly sophisticated and costly remedies. In recent years, the limitations of broadcast antenna technology on the quality, capacity, and coverage of wireless systems have prompted an evolution in the fundamental design and role of the antenna in a wireless system.

1.3.2 Directional Antennas

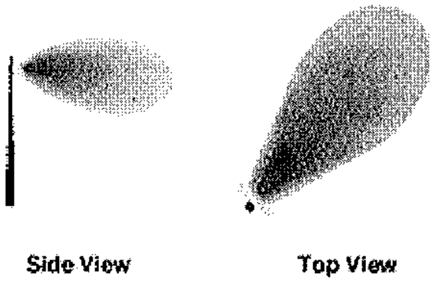


Fig 1.3 Directional Antenna and Coverage Pattern

A single antenna can also be constructed to have certain fixed preferential transmission and reception directions. As an alternative to the brute force method of adding new transmitter sites, many conventional antenna towers today split, or sectorize cells. A 360°

area is often split into three 120° subdivisions, each of which is covered by a slightly less broadcast method of transmission.

All else being equal, sector antennas provide increased gain over a restricted range of azimuths as compared to an omnidirectional antenna. This is commonly referred to as antenna element gain and should not be confused with the processing gains associated with smart antenna systems.

While sectorized antennas multiply the use of channels, they do not overcome the major disadvantages of standard omnidirectional antenna broadcast such as cochannel interference,

There are many variations of antennas. Below are a few basic models.

- The **isotropic radiator** is a purely theoretical antenna that radiates equally in all directions. It is considered to be a point in space with no dimensions and no mass. This antenna cannot physically exist, but is useful as a theoretical model for comparison with all other antennas. Most antennas' gains are measured with reference to an isotropic radiator, and are rated in dBi (decibels with respect to an isotropic radiator).
- The **dipole antenna** is simply two wires pointed in opposite directions arranged either horizontally or vertically, with one end of each wire connected to the radio and the other end hanging free in space. Since this is the simplest practical antenna, it is also used as a reference model for other antennas; gain with respect to a dipole is labeled as dBd. Generally, the dipole is considered to be omnidirectional in the plane perpendicular to the axis of the antenna, but it has deep nulls in the directions of the axis. Variations of the dipole include the folded dipole, the half wave antenna, the ground plane antenna, the whip, and the J-pole.
- The **Yagi-Uda antenna** is a directional variation of the dipole with parasitic elements added which are functionality similar to adding a reflector and lenses (directors) to focus a filament light bulb.
- The **random wire antenna** is simply a very long (at least one quarter wavelength) wire with one end connected to the radio and the other in free space,

arranged in any way most convenient for the space available. Folding will reduce effectiveness and make theoretical analysis extremely difficult.

- The **horn** is used where high gain is needed, the wavelength is short (microwave) and space is not an issue. Horns can be narrow band or wide band, depending on their shape. A horn can be built for any frequency, but horns for lower frequencies are typically impractical. Horns are also frequently used as reference antennas.
- The **parabolic antenna** consists of an active element at the focus of a parabolic reflector to reflect the waves into a plane wave. Like the horn it is used for high gain, microwave applications, such as satellite dishes.
- The **patch antenna** consists mainly of a square conductor mounted over a groundplane. Another example of a planar antenna is the tapered slot antenna (TSA), as the Vivaldi-antenna.

CHAPTER 2

2. Smart Antenna Systems

2.1 Definition

A smart antenna system combines multiple antenna elements with a signal processing capability to optimize its radiation and/or reception pattern automatically in response to the signal environment.

2.2 A Useful Analogy for Smart Antennas

For an intuitive grasp of how an adaptive antenna system works, close your eyes and converse with someone as they move about the room. You will notice that you can determine their location without seeing them because of the following:

a) You hear the speaker's signals through your two ears, your acoustic sensors.
b) The voice arrives at each ear at a different time.
c) Your brain, a specialized signal processor, does a large number of calculations to correlate information and compute the location of the speaker.

Your brain also adds the strength of the signals from each ear together, so you perceive sound in one chosen direction as being twice as loud as everything else.

Adaptive antenna systems do the same thing, using antennas instead of ears. As a result, 8, 10, or 12 ears can be employed to help fine-tune and turn up signal information. Also, because antennas both listen and talk, an adaptive antenna system can send signals back in the same direction from which they came. This means that the antenna system cannot only hear 8 or 10 or 12 times louder but talk back more loudly and directly as well.

Going a step further, if additional speakers joined in, your internal signal processor could also tune out unwanted noise (interference) and alternately focus on one conversation at a time. Thus, advanced adaptive array systems have a similar ability to differentiate between desired and undesired signals.

2.3 Antenna Systems

How can an antenna be made more intelligent? First, its physical design can be modified by adding more elements. Second, the antenna can become an antenna system that can be designed to shift signals before transmission at each of the successive elements so that the antenna has a composite effect. This basic hardware and software concept is known as the phased array antenna. The following summarizes antenna developments in order of increasing benefits and intelligence.

2.3.1 Sectorized Systems

Sectorized antenna systems take a traditional cellular area and subdivide it into sectors that are covered using directional antennas looking out from the same base station location. Operationally, each sector is treated as a different cell, the range of which is greater than in the omnidirectional case. Sector antennas increase the possible reuse of a frequency channel in such cellular systems by reducing potential interference across the original cell, and they are widely used for this purpose. As many as six sectors per cell have been used in practical service. When combining more than one of these directional antennas, the base station can cover all directions.

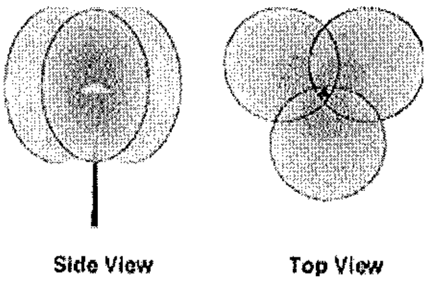


Figure 2.1 Sectorized Antenna and Coverage Patterns

2.3.2 Diversity Systems

In the next step toward smart antennas, the diversity system incorporates two antenna elements at the base station. Diversity offers an improvement in the effective strength of the received signal by using one of the following two methods:

2.3.2.1 Switched diversity

Assuming that at least one antenna will be in a favorable location at a given moment, this system continually switches between antennas (connects each of the receiving channels to the best serving antenna) so as always to use the element with the largest output. While reducing the negative effects of signal fading, they do not increase gain since only one antenna is used at a time.

2.3.2.2 Diversity combining

This approach corrects the phase error in two multipath signals and effectively combines the power of both signals to produce gain. Other diversity systems, such as maximal ratio combining systems, combine the outputs of all the antennas to maximize the ratio of combined received signal energy to noise. Because macrocell-type base stations historically put out far more power on the downlink (base station to user) than mobile terminals can generate on the reverse path, most diversity antenna systems have evolved only to perform in uplink (user to base station).

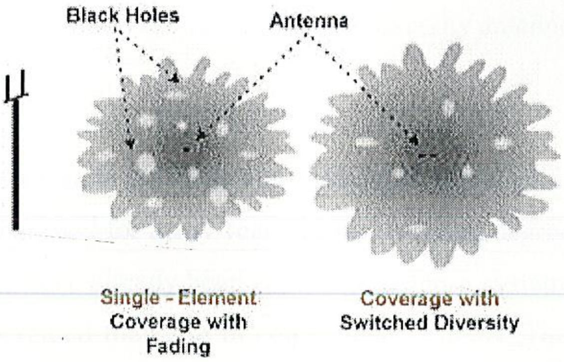


Fig 2.2 Switched Diversity Coverage with Fading and Switched Diversity

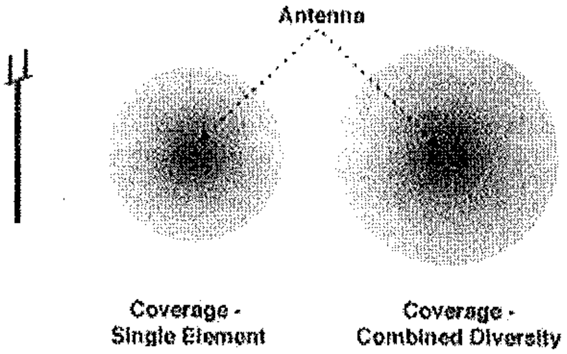


Fig 2.3 Combined Diversity Effective Coverage Pattern with Single Element and Combined Diversity

Diversity antennas merely switch operation from one working element to another. Although this approach mitigates severe multipath fading, its use of one element at a time offers no uplink gain improvement over any other single element approach. In high-interference environments, the simple strategy of locking onto the strongest signal or extracting maximum signal power from the antennas is clearly inappropriate and can result in crystal-clear reception of an interferer rather than the desired signal.

The need to transmit to numerous users more efficiently without compounding the interference problem led to the next step of the evolution antenna systems that intelligently integrate the simultaneous operation of diversity antenna elements.

2.4 Smart Antennas

The concept of using multiple antennas and innovative signal processing to serve cells more intelligently has existed for many years. In fact, varying degrees of relatively costly smart antenna systems have already been applied in defense systems. Until recent years, cost barriers have prevented their use in commercial systems. The advent of powerful low-cost digital signal processors (DSPs), general-purpose processors (and ASICs), as well as innovative software-based signal-processing techniques (algorithms) have made intelligent antennas practical for cellular communications systems.

Today, when spectrally efficient solutions are increasingly a business imperative, these systems are providing greater coverage area for each cell site, higher rejection of interference, and substantial capacity improvements.

2.5 What Is a Smart Antenna System?

In truth, antennas are not smart—antenna systems are smart. Generally collocated with a base station, a smart antenna system combines an antenna array with a digital signal-processing capability to transmit and receive in an adaptive, spatially sensitive manner. In other words, such a system can automatically change the directionality of its radiation patterns in response to its signal environment. This can dramatically increase the performance characteristics (such as capacity) of a wireless system. A smart antenna is an array of antenna elements connected to a digital signal processor. Such a configuration dramatically enhances the capacity of a wireless link through a combination of diversity gain, array gain, and interference suppression. Increased capacity translates to higher data rates for a given number of users or more users for a given data rate per user.

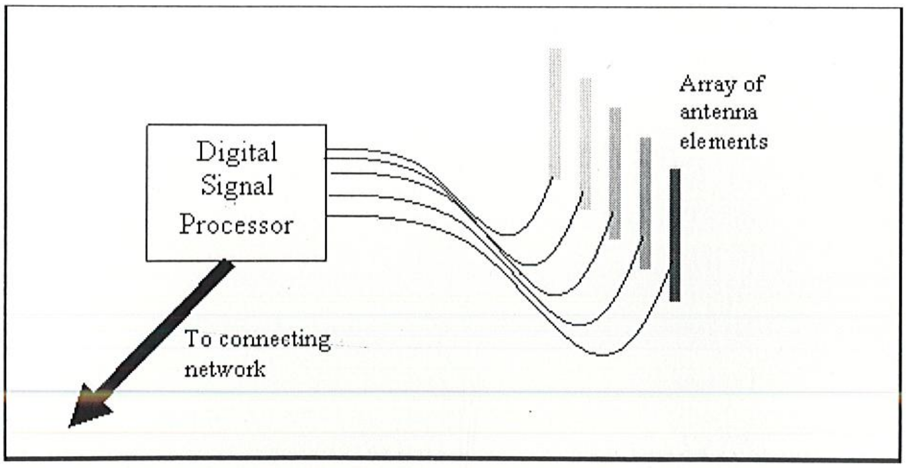


Fig 2.4 Block Diagram of the use of Smart Antenna System

2.6 How Many Types of Smart Antenna Systems Are There?

Terms commonly heard today that embrace various aspects of a smart antenna system technology include intelligent antennas, phased array, SDMA, spatial processing, digital beamforming, adaptive antenna systems, and others. Smart antenna systems are customarily categorized, however, as either switched beam or adaptive array systems. The following are distinctions between the two major categories of smart antennas regarding the choices in transmit strategy:

a) **switched beam:-** a finite number of fixed, predefined patterns or combining strategies (sectors).

b) **adaptive array:-** an infinite number of patterns (scenario-based) that are adjusted in real time.

CHAPTER 3

3. BEAMFORMING BASICS

Beam forming is the term used to describe the application of weights to the inputs of an array of antennas to focus the reception of the antenna array in a certain direction, called the look direction or the main lobe. More importantly, other signals of the same carrier frequency from other directions can be rejected. These effects are all achieved electronically and no physical movement of the receiving antennas is necessary. In addition, multiple beam formers focused in different directions can share a single antenna array one set of antennas can service multiple calls of the same carrier. It is no coincidence that the number of elements in the above diagram equals the number of incoming signals. A beam former of L antenna elements is capable of accepting one signal and reliably rejecting L-1 signals. A greater number of interfering signals will diminish the performance of the beam former.

Beam forming presents several advantages to antenna design .Firstly, space division multiple access (SDMA) is achieved since a beamformer can steer its look direction towards a certain signal. Other signals from different directions can reuse the same carrier frequency. Secondly, because the beamformer is focused in a particular direction, the antenna sensitivity can be increased for a better signal to noise ratio, especially when receiving weak signals. Thirdly, signal interference is reduced due to the rejection of undesired signals. For the uplink case of transmitting from the antenna array to a mobile telephone, system interference is reduced since the signal is only transmitted in the look direction. A digital beamformer is one that operates in the digital domain. Traditionally, beam formers were implemented in analog; the weights were determined and applied to the antenna inputs via analog circuitry. With digital beam forming, the antenna signals are individually translated from Radio Frequencies (RF) to Intermediate Frequencies (IF), digitized and then down-converted to base-band I and Q components. A beam forming algorithm implemented on one or more digital signal processors then processes the I and Q components to determine a set of weights for the input signals. The input signals are then multiplied by the weights and summed to output the signal of interest(SOI). One of the foremost advantages offered by the software radio technology is flexibility. Because beam forming is implemented in software, it is possible to investigate a wide range of beam forming algorithms without the need to modify the system hardware for every algorithm. Consequently, researchers can focus their efforts on improving the performance of the beam forming algorithms rather than on designing new hardware, which can be a very expensive and time consuming process. A complete description of the RLS algorithm can be found in .This algorithm was chosen for its fast convergence rate and ability to process the input signal before demodulation. While the first reason is important especially when the environment is changing rapidly, the later reason decreases the algorithm dependency on a specific air interface.

3.1 Applications in Mobile Communications:

A space-time processor ('smart 'antenna') is capable of forming transmit/receive beams towards the mobile of interest. At the same time it is possible to place spatial nulls in the direction of unwanted interferences. This capability can be used to improve the performance of a mobile communication system Increased antenna gain The 'smart' antenna forms transmit and receive beams. Therefore, the 'smart' antenna has a higher gain than a conventional omni-directional antenna. The higher gain can be used to either increase the effective coverage, or to increase the receiver sensitivity, which in turn can be exploited to reduce transmit power and electromagnetic radiation in the network. Decreased inter-symbol-interference (ISI) Multipath propagation in mobile radio environments leads to ISI. Using transmit and receive beams that are directed towards the mobile of interest reduces the amount of Multipath and ISI. Decreased co-channel-interference (CCI) 'Smart' antenna transmitters emit less interference by only sending RF power in the desired directions. Furthermore, 'smart' antenna receivers can reject interference by looking only in the direction of the desired source. Consequently 'smart' antennas are capable of decreasing CCI. A significantly reduced CCI can be taken advantage of by Spatial Division Multiple Access (SDMA) . The same frequency band can be re-used in more cells, i.e. the so called frequency re-use distance can be decreased. This technique is called Channel Re-use via Spatial Separation. Several mobiles can share the same frequency within a cell. Multiple signals arriving at the base station can be separated by the base station receiver as long as their angular separation is bigger than the transmit / receive beam widths .The beams that are hatched identically use the same frequency band. This technique is called Channel Re-use via Angular Separations.

3.2 What Are Switched Beam Antennas?

Switched beam antenna systems form multiple fixed beams with heightened sensitivity in particular directions. These antenna systems detect signal strength, choose from one of several predetermined, fixed beams, and switch from one beam to another as the mobile moves throughout the sector.

Instead of shaping the directional antenna pattern with the metallic properties and physical design of a single element (like a sectorized antenna), switched beam systems combine the outputs of multiple antennas in such a way as to form finely sectorized (directional) beams with more spatial selectivity than can be achieved with conventional, single-element approaches.

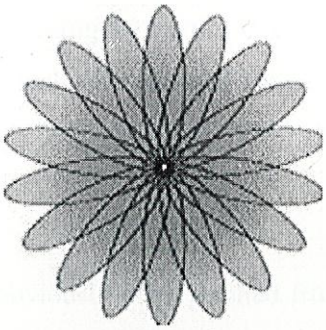


Fig 3.1 Switched Beam System Coverage Patterns (Sectors)

3.3 What Are Adaptive Array Antennas?

Adaptive antenna technology represents the most advanced smart antenna approach to date. Using a variety of new signal-processing algorithms, the adaptive system takes advantage of its ability to effectively locate and track various types of signals to dynamically minimize interference and maximize intended signal reception. Both systems attempt to increase gain according to the location of the user; however, only the adaptive system provides optimal gain while simultaneously identifying, tracking, and minimizing interfering signals.

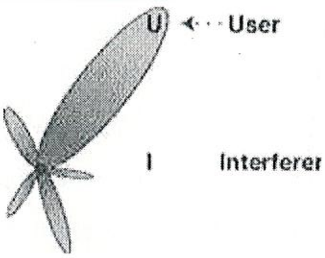


Fig 3.2 Adaptive Array Coverage: A Representative Depiction of a Main Lobe Extending Toward a User with a Null Directed Toward a Co channel Interferer

3.4 What Do They Look Like?

Omnidirectional antennas are obviously distinguished from their intelligent counterparts by the number of antennas (or antenna elements) employed. Switched beam and adaptive array systems, however, share many hardware characteristics and are distinguished primarily by their adaptive intelligence. To process information that is directionally sensitive requires an array of antenna elements (typically 4 to 12), the inputs from which are combined to control signal transmission adaptively. Antenna elements can be arranged in linear, circular, or planar configurations and are most often installed at the base station, although they may also be used in mobile phones or laptop computers.

3.5 What Makes Them So Smart?

A simple antenna works for a simple RF environment. Smart antenna solutions are required as the number of users, interference, and propagation complexity grow. Their smarts reside in their digital signal-processing facilities. Like most modern advances in electronics today, the digital format for manipulating the RF data offers numerous advantages in terms of accuracy and flexibility of operation. Speech starts and ends as analog information. Along the way, however, smart antenna systems capture, convert, and modulate analog signals for transmission as digital signals and reconvert them to analog information on the other end. The smart antenna works as follows. Each antenna element "sees" each propagation path differently, enabling the collection of elements to distinguish individual paths to within a certain resolution. As a consequence, smart antenna transmitters can encode independent streams of data onto different paths or linear combinations of paths, thereby increasing the data rate, or they can encode data redundantly onto paths that fade independently to protect the receiver from catastrophic signal fades, thereby providing diversity gain. A smart antenna receiver can decode the data from a smart antenna transmitter this is the highest-performing configuration or it can simply provide array gain or diversity gain to the desired signals transmitted from conventional transmitters and suppress the interference. No manual placement of antennas is required. The smart antenna electronically adapts to the environment by looking for pilot tones or beacons or by recovering certain characteristics (such as a known alphabet or constant envelope) that the transmitted signal is known to have. The smart antenna can also separate the signals from multiple users who are separated in space (i.e. by distance) but who use the same radio channel (i.e. center frequency, time-slot, and/or code); this application is called Space- division multiple access (SDMA). In adaptive antenna systems, this fundamental signal-processing capability is augmented by advanced techniques (algorithms) that are applied to control operation in the presence of complicated combinations of operating conditions.

3.6 The Goals of a Smart Antenna System

The dual purpose of a smart antenna system is to augment the signal quality of the radio-based system through more focused transmission of radio signals while enhancing capacity through increased frequency reuse.

3.7 Features and Benefits of Smart Antenna Systems

1) **signal gain**:- Inputs from multiple antennas are combined to optimize available power required to establish given level of coverage.
2) **better range/coverage**:- Focusing the energy sent out into the cell increases base station range and coverage. Lower power requirements also enable a greater battery life and smaller/lighter handset size.
3) **Interference rejection**:- Antenna pattern can be generated toward cochannel interference sources, improving the signal-to- interference ratio of the received signals.
4) **increased capacity**:- Precise control of signal nulls quality and mitigation of interference combine to frequency reuse reduce distance (or cluster size), improving capacity. Certain adaptive technologies (such as space division multiple access) support the reuse of frequencies within the same cell.
5) **Spatial diversity:-** Composite information from the array is used to minimize fading and other undesirable effects of multipath propagation.
6) **multipath rejection**:- can reduce the effective delay spread of the channel, allowing higher bit rates to be supported without the use of an equalizer
7) **power efficiency**:- combines the inputs to multiple elements to optimize available processing gain in the downlink (toward the user).
8) **reduced expense**:- Lower amplifier costs, power consumption, and higher reliability will result.

CHAPTER 4

4. Array Fundamentals

Smart antennas are composed of a collection of two or more antennas working in concert to establish a unique radiation pattern for the electromagnetic environment at hand. The antenna elements are allowed to work in concert by means of array element phasing, which is accomplished with hardware or is performed digitally. Arrays of antennas can assume any geometric form. The various array geometries of common interest are linear arrays, circular arrays, planar arrays, and conformal arrays.

4.1 Linear Arrays

The simplest array geometry is the linear array. Thus, all elements are aligned along a straight line and generally have a uniform inter element spacing. Linear arrays are the simplest to analyze and many valuable insights can be gained by understanding their behavior. The minimum length linear array is the 2-element array.

4.1.1 Two element array

The most fundamental and simplest array to analyze is the two-element array. The two-element array demonstrates the same general behavior as much larger arrays and is a good starting point in order to understand the phase relationship between adjacent array elements. Figure below shows two vertically polarized infinitesimal dipoles aligned along the *y* axis and separated by a distance *d.*

The field point is located at a distance *r* from the origin such that $r >> d$. We can therefore assume that the distance vectors $\bar{r}1$, $\bar{r}$, and $\bar{r}2$ are all approximately parallel to each other.

We can therefore make the following approximations:

$r1 \approx r + d/2 \sin\theta$

$r2 \approx r - d/2\sin\theta$

Let us additionally assume that the electrical phase of element 1 is $-\delta/2$ such that the phasor current in element 1 is $I_0e^{-j\,\delta/2}$. The electrical phase of element 2 is $+\delta/2$ such that the phasor current in element 2 is $I_0e^{+j\,\delta/2}$. We can now find the distant electric field by using superposition as applied to these two dipole elements.

Assuming that $r1 \approx r1 \approx r$, we can now find the total electric field.

$$E_{\theta} = (jk\eta\, I_0e^{-j\,\delta/2}L\sin\theta/4\pi r1)\, e^{-jkr1} + (jk\eta\, I_0e^{+j\,\delta/2}L\sin\theta/4\pi r2)\, e^{-jkr2}$$

$$= (jk\eta\, I_0L\sin\theta/4\pi r)\, e^{-jkr}[e^{-j\,(kd\sin\theta+\delta)/2} + e^{j\,(kd\sin\theta+\delta)/2}]$$

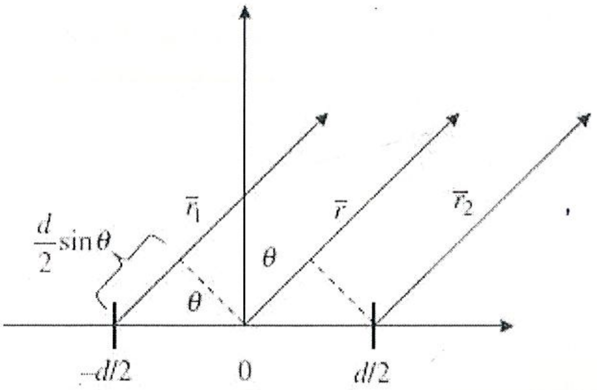


Fig 4.1 Two infinitesimal dipoles.

where δ = electrical phase difference between the two adjacent elements

L = dipole length

θ = angle as measured from the z axis in spherical coordinates

d = element spacing

We can further simplify such that

$$E_\theta = (jk\eta\ I_0L\sin\theta/4\pi r)\ e^{-jkr}\,[2\cos((kd\sin\theta + \delta)/2))]$$

Where

Element factor is

$$(jk\eta\ I_0L\sin\theta/4\pi r)\ e^{-jkr}$$

And array factor is

$$[2\cos((kd\sin\theta + \delta)/2))]$$

The element factor is the far field equation for one dipole and the array factor is the pattern function associated with the array geometry.

The distant field from an array of identical elements can always be broken down into the product of the element factor (EF) and the array factor (AF). The very fact that the antenna pattern can be multiplied by the array factor pattern demonstrates a property called pattern multiplication. Thus, the far field pattern of any array of antennas is always given by (EF) × (AF). The AF is dependent on the geometric arrangementof the array elements, the spacing of the elements, and the electricalphase of each element.

4.1.2 Uniform *N*-element linear array

The more general linear array is the *N*-element array. For simplification purposes, we will assume that all elements are equally spaced and have equal amplitudes. Later we may allow the antenna elements to have any arbitrary amplitude. Figure below shows an *N*-element linear array composed of isotropic radiating antenna elements.

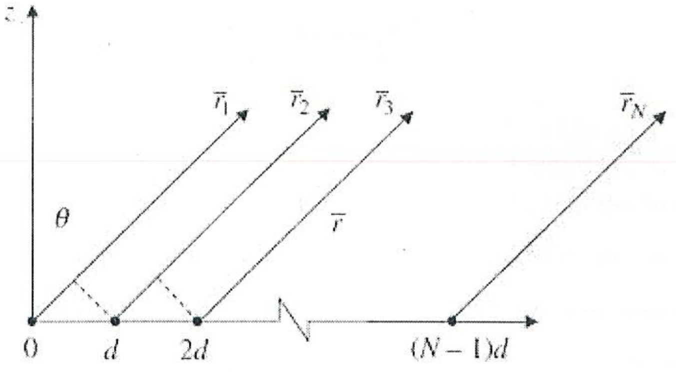


Fig 4.2 N-element linear array

It is assumed that the nth element leads the $(n-1)$ element by an electrical phase shift of δ radians. This phase shift can easily be implemented by shifting the phase of the antenna current for each element.

Assuming far field conditions such that $r >> d$, we can derive the array factor as follows:

$$\mathrm{AF} = 1 + e^{j(kd\sin\theta+\delta)} + e^{j2(kd\sin\theta+\delta)} + \cdots + e^{j(N-1)(kd\sin\theta+\delta)}$$

where δ is the phase shift from element to element.

This series can more concisely be expressed by

$$\mathrm{AF} = {}_{n=1}\sum^{N} e^{j(N-1)(kd\sin\theta+\delta)}$$

where $\psi = kd\sin\theta + \delta$.

It should be noted that if the array is aligned along the z-axis then

$\psi = kd\cos\theta + \delta$.

Since each isotropic element has unity amplitude, the entire behavior of this array is dictated by the phase relationship between the elements. The phase is directly proportional to the element spacing in wavelengths.

Let us begin by defining the array vector.

$$^{-}a(\theta) = [1 \quad e^{j(kd\sin\theta+\delta)} \quad \ldots\ldots \quad e^{j(N-1)(kd\sin\theta+\delta)}]^{T}$$

where [ ]*T* signifies the transpose of the vector within the brackets. The vector $^{-}a(\theta)$ is a Vandermonde vector because it is in the form [1 z . . . $z(N-1)$]. In the literature the array vector has been alternatively called: the array steering vector, the array propagation vector, the array response vector, and the array manifold vector. For simplicity's sake, we will call $^{-}a(\theta)$ the array vector. Therefore, the array factor, can alternatively be expressed as the sum of the elements of the array vector.

$\mathrm{AF} = \mathrm{sum}(^{-}a(\theta))$

We may simplify the expression by multiplying both sides by $e^{j\psi}$ such that

$$e^{j\psi}\,\mathrm{AF} = e^{j\psi} + e^{j2\psi} + \cdots + e^{jN\psi}$$

Subtracting yields

$(e^{j\psi} - 1)\mathrm{AF} = (e^{jN\psi} - 1)$

The array factor can now be rewritten.

$$\begin{aligned}\mathrm{AF} &= (e^{jN\psi} - 1)/(e^{j\psi} - 1)\\ &= e^{j\,N/2\,\psi}(e^{j\,N/2\,\psi} - e^{-j\,N/2\,\psi})/e^{j\,\psi/2}(e^{j\,\psi/2} - e^{-j\,\psi/2})\\ &= e^{j(N-1)\psi/2}\sin(N\psi/2/\sin\psi/2)\end{aligned}$$

$e^{j(N-1)\psi/2}$ term accounts for the fact that the physical center of the array is located at $(N-1)d/2$. This array center produces a phase shift of $(N-1)\psi/2$ in the array factor. If the array is centered about the origin, the physical center is at 0 and Eq. can be simplified to become

$$\mathrm{AF} = \sin(N\psi/2/\sin\psi/2)$$

The maximum value of AF is when the argument $\psi = 0$. In that case AF = N. This is intuitively obvious since an array of N elements should have a gain of N over a single element. We may normalize the AF to be reexpressed as

$$AF_n = 1/N \sin(N \psi /2/\sin\psi/2)$$

In the cases where the argument $\psi/2$ is very small, we can invoke the small argument approximation for the sin ($\psi/2$) term to yield an approximation

$$AF_n \approx \sin(N \psi /2/N\psi/2)$$

CHAPTER 5

5. Methodology

Traditional array antennas, where the main beam is steered to directions of interest, are called phased arrays, beamsteered arrays, or scanned arrays. The beam is steered via phase shifters and in the past these phase shifters were often implemented at RF frequencies. This general approach to phase shifting has been referred to as electronic beamsteering because of the attempt to change the phase of the current directly at each antenna element.

Smart antenna patterns are controlled via algorithms based upon certain criteria. These criteria could be maximizing the signal-to-interference ratio (SIR), minimizing the variance, minimizing the meansquare error (MSE), steering toward a signal of interest, nulling the interfering signals, or tracking a moving emitter to name a few. The implementation of these algorithms can be performed electronically through analog devices but it is generally more easily performed using digital signal processing. This requires that the array outputs be digitized through the use of an A/D converter. This digitization can be performed at either IF or baseband frequencies. Since an antenna pattern (or beam) is formed by digital signal processing, this process is often referred to as digital beamforming. Figure below contrasts a traditional electronically steered array with a DBF array or smart antenna.

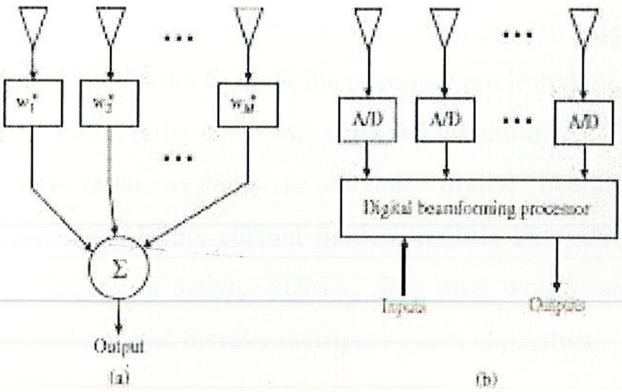


Figure 5.1 (*a*) Analog beamforming, (*b*) Digital beamforming.

When the algorithms used are adaptive algorithms, this process is referred to as adaptive beamforming. Adaptive beamforming is a subcategory under the more general subject of digital beamforming. Digital beamforming has been applied to radar systems, sonar systems, and communications systems to name a few. The chief advantage of digital beamforming is that phase shifting and array weighting can be performed on the digitized data rather than by being implemented in hardware. On receive, the beam is formed in the data processing rather than literally being forming in space. The digital beamforming method cannot be strictly called electronic steering since no effort is made to directly shift the phase of the antenna element currents. Rather, the phase shifting is computationally performed on the digitized signal. If the parameters of operation are changed or the detection criteria are modified, the beamforming can be changed by simply changing an algorithm rather than by replacing hardware.

Adaptive beamforming is generally the more useful and effective beamforming solution because the digital beamformer merely consists of an algorithm which dynamically optimizes the array pattern according to the changing electromagnetic environment. Conventional array static processing systems are subject to degradation by various causes. The array SNR can be severely degraded by the presence of unwanted interfering signals, electronic countermeasures, clutter returns, reverberation returns (in acoustics), or multipath interference and fading. An adaptive array system consists of the antenna array elements terminated in an adaptive processor which is designed to specifically maximize certain criteria. As the emitters move or change, the adaptive array updates and compensates iteratively in order to track the changing environment. Many current modern radar systems still rely on older electronic scanning technologies. Recent efforts are being exerted to modify radar systems to include digital beamforming and adaptive beamforming techniques. While current modern mobile base stations tend to use older fixed beam technologies to satisfy SDMA, they also would benefit from the use of modern adaptive methods and thereby increase system capacities.

5.1 Fixed Weight Beamforming Basics

5.1.1 Maximum signal-to-interference ratio

One criterion which can be applied to enhancing the received signal and minimizing the interfering signals is based upon maximizing the SIR. It is intuitive that if we can cancel all interference by placing nulls at their angles of arrival, we will automatically maximize the SIR. Let us assume an $N = 3$-element array with one fixed known desired source and two fixed undesired interferers. All signals are assumed to operate at the same carrier frequency. Let us assume a three-element array with the desired signal and interferers as shown in Fig. below

The array vector is given by

$$a^{-} = [e^{-jkd\sin\theta}\ 1\ e^{jkd\sin\theta}]^{T}$$

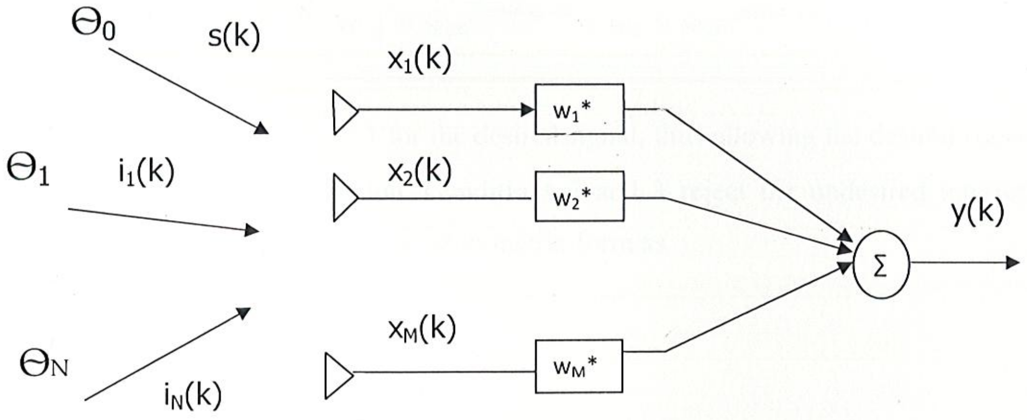


Fig 5.2 Three-element array with desired and interfering signals

The, as yet to be determined, array weights for optimization are given by

$$\bar{w}^H = [w_1\ w_2\ w_3]$$

Therefore, the general total array output is given as

$$y = \bar{w}^H \cdot \bar{a} = w_1 e^{-jkd\sin\theta} + w_2 + w_3 e^{jkd\sin\theta}$$

The array output for the desired signal will be designated by y_s whereas the array output for the interfering or undesired signals will be designated by y_1 and y_2. Since there are three unknown weights, there must be three conditions satisfied.

Condition 1: $y_s = \bar{w}^H \cdot \bar{a}_0 = w_1 e^{-jkd\sin\theta 0} + w_2 + w_3 e^{jkd\sin\theta 0} = 1$

Condition 2: $y_1 = \bar{w}^H \cdot \bar{a}_1 = w_1 e^{-jkd\sin 01} + w_2 + w_3 e^{jkd\sin\theta 1} = 0$

Condition 3: $y_2 = \bar{w}^H \cdot \bar{a}_2 = w_1 e^{-jkd\sin 02} + w_2 + w_3 e^{jkd\sin 02} = 0$

Condition 1 demands that $y_s = 1$ for the desired signal, thus allowing the desired signal to be received without modification. Conditions 2 and 3 reject the undesired interfering signals. These conditions can be recast in matrix form as

$$\bar{w}^H \cdot \bar{A} = \bar{u}_l^T$$

where

$\bar{A} = [\bar{a}_0\ \bar{a}_1\ \bar{a}_2]$ = matrix of steering vectors

$\bar{u}_1 = [1\ 0 \cdots 0]^T$ = Cartesian basis vector

One can invert the matrix to find the required complex weights w_1, w_2, and w_3 by using

$$\bar{w}^H = \bar{u}_1^T \bar{A}^{-1}$$

As an example, if the desired signal is arriving from $\theta_0 = 0°$ while $\theta_1 = -45°$ and $\theta_2 = 60°$, the necessary weights can be calculated to be

$$[\, w1 \;\; w2 \;\; w3 \,] = [\, .28 - .07i \;\; .45 \;\; .28 + .07i \,]$$

The array factor is shown plotted in Fig. below

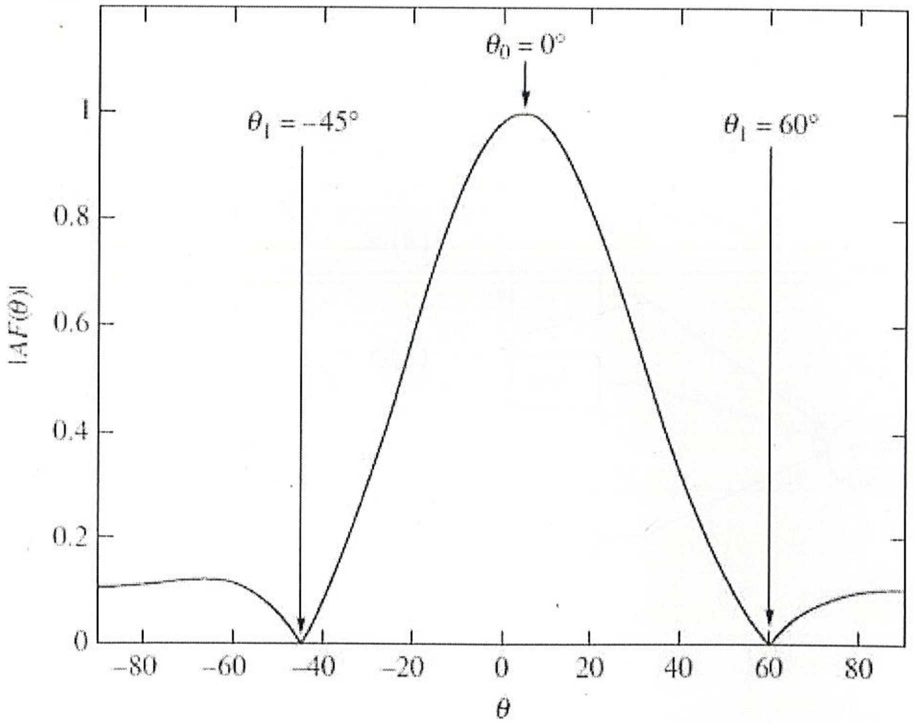


Fig 5.3 Array factor plot

The previous development is predicated on the fact that the desired signal and the total of the interfering signals make $\bar{A}$ an invertible square matrix. $\bar{A}$ must be an $N \times N$ matrix with N-array elements and N-arriving signals. In the case where the number of interferers is less than $M-1$, Godara has provided an equation which gives an estimate of the weights. However, his formulation requires noise be added in the system because the matrix inversion will be singular otherwise. Using the Godara method we have :

$$w^{-H} = u_1^{-T} \cdot A^{-H}(A^{-} \cdot A^{-H} + \sigma_n^2 \Gamma^{-})^{-1}$$

where u_1^{-T} is the Cartesian basis vector whose length equals the total number of sources.

5.1.2 Including Additive White Gaussian Noise

The above basic sidelobe canceling scheme works through an intuitive application of the array steering vector for the desired signal and interfering signals. However, by normally maximizing the SIR, we can derive the analytic solution for all arbitrary cases.

The general non-adaptive conventional narrowband array is shown
in Fig. below

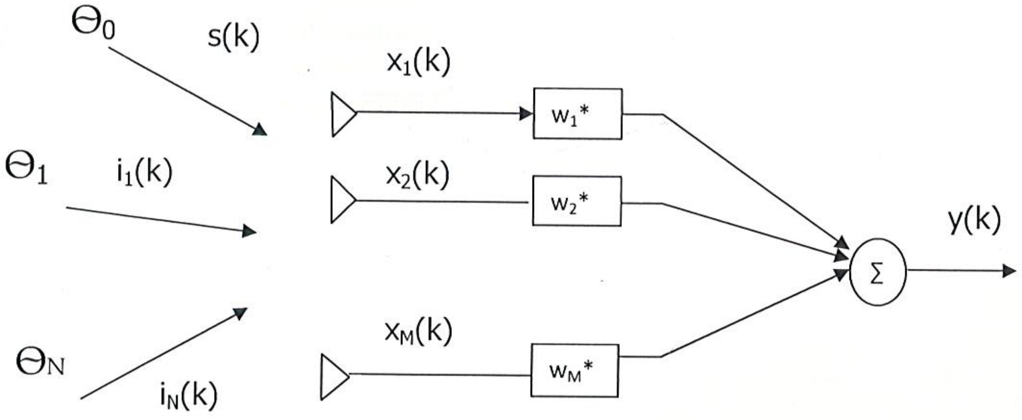


Fig 5.4 Non-adaptive narrowband array

Figure shows one desired signal arriving from the angle θ_0 and N interferers arriving from angles $\theta_1, \ldots, \theta_N$. The signal and the interferers are received by an array of M elements with M potential weights. Each received signal at element m also includes additive Gaussian noise. Time is represented by the kth time sample. Thus, the weighted array output y can be given in the following form:

$$y(k) = \bar{w}^H \cdot \bar{x}(k)$$

where

$$\begin{aligned}\bar{x}(k) &= \bar{a}_0 s(k) + [\bar{a}_1\ \bar{a}_2 \cdots \bar{a}_N] \cdot [i_1(k)\ i_2(k) \ldots\ i_N(k)]^{\mathrm{T}} + \bar{n}(k) \\ &= \bar{x}_s(k) + \bar{x}_i(k) + \bar{n}(k)\end{aligned}$$

with

$\bar{w} = [w_1\ w_2 \cdots w_M]^T$ = array weights

$\bar{x}_s(k)$ = 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 above equation using the expanded notation

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

where

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

It is initially assumed that all arriving signals are monochromatic and the total number of arriving signals $N + 1 \leq M$. It is understood that the arriving signals are time varying and thus our calculations are based upon k-time snapshots of the incoming signal. Obviously, if the emitters are moving, the matrix of steering vectors is changing with time and the corresponding arrival angles are changing.

We can calculate the array correlation matrices for both the desired signal ($\bar{R}_{ss}$) and the undesired signals ($\bar{R}_{uu}$). These matrices are often called the array covariance matrices. However, the covariance matrix is a mean removed correlation matrix. If the process is ergodic and the time average is utilized, the correlation matrices can be defined with the time average notation as $\hat{R}_{ss}$ and $\hat{R}_{uu}$

The weighted array output power for the desired signal is given by

$$\sigma_s^2 = E[|\bar{w}^H . \bar{x}_s|^2]$$
$$= \bar{w}^H . \bar{R}_{ss} . \bar{w}$$

where

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

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

$$\sigma_u^2 = E[|\bar{w}^H . \bar{u}|^2]$$
$$= \bar{w}^H . \bar{R}_{uu} . \bar{w}$$

where it can be shown that

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

with

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

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

The (SIR) is defined as the ratio of the desired signal power divided by the undesired signal power.

$$\text{SIR}=\sigma_s^2/\sigma_u^2$$
$$=(\bar{w}^{H} . \bar{R}_{ss} . \bar{w})/(\bar{w}^{H} . \bar{R}_{uu} . \bar{w})$$

5.2 Adaptive Beamforming

The fixed beamforming approaches, mentioned above, which included the maximum SIR, was assumed to apply to fixed arrival angle emitters. If the arrival angles don't change with time, the optimum array weights won't need to be adjusted. However, if the desired arrival angles change with time, it is necessary to devise an optimization scheme that operates *on-the-fly* so as to keep recalculating the optimum array weights. The receiver signal processing algorithm then must allow for the continuous adaptation to an ever-changing electromagnetic environment. The adaptive algorithm takes the fixed beamforming process one step further and allows for the calculation of continuously updated weights. The adaptation process must satisfy a specified optimization criterion.

5.2.1 Least mean squares

The least mean squares algorithm is a gradient based approach.Gradient based algorithms assume an established quadratic performance surface. When the performance surface is a quadratic function of the array weights, the performance surface $J(\bar{w})$ is in the shape of an elliptic paraboloid having one minimum. One of the best ways to establish the minimum is through the use of a gradient method. We can establish the performance surface (cost function) by again finding the MSE. The error, as indicated in Fig. below, is

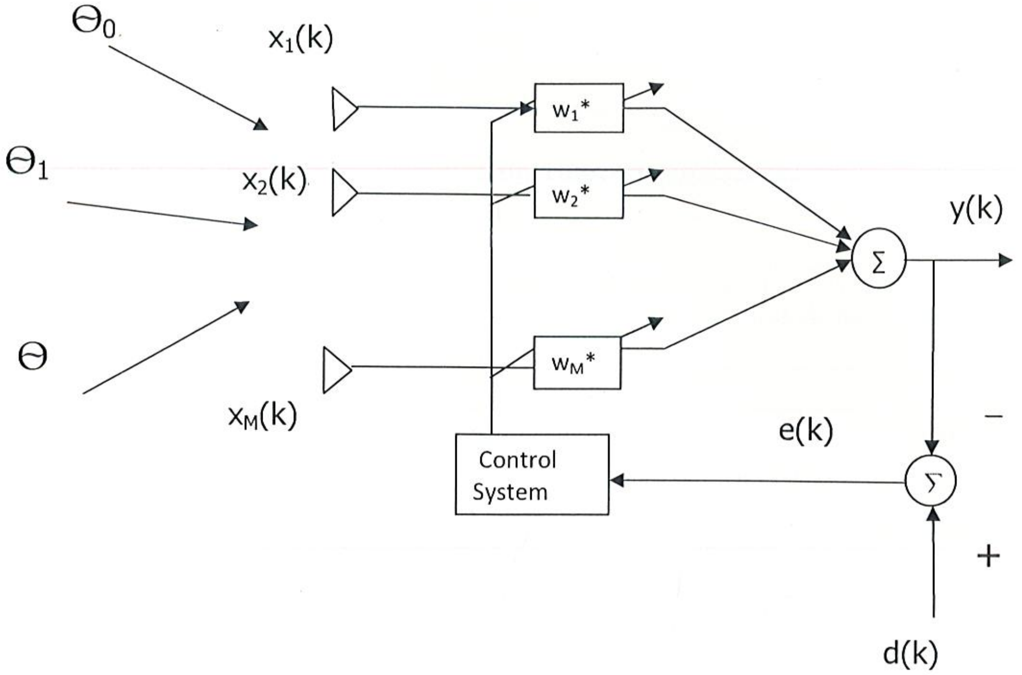


Fig 5.5 Least mean square method

$$\varepsilon(k) = d(k) - w^{-H}(k)x^{-}(k)$$

The squared error is given as

$$|\varepsilon(k)|^2 = |d(k) - w^{-H}(k)x^{-}(k)|^2$$

Momentarily, we will suppress the time dependence. The cost function is given as

$$J(w^{-}) = D - 2w^{-H}r^{-} + w^{-H}R_{xx}w^{-}$$

Where

$$D = E[|d|^2]$$

We may employ the gradient method to locate the minimum. Thus

$$\nabla_{\bar{w}}(J(\bar{w})) = 2R_{xx}\bar{w} - 2\bar{r}$$

The minimum occurs when the gradient is zero. Thus, the solution for the weights is the optimum Wiener solution as given by

$$\bar{w}_{opt} = R^{-1}_{xx}\,\bar{r}$$

The solution in Eq. above is predicated on our knowledge of all signal statistics and thus in our calculation of the correlation matrix.

In general, we do not know the signal statistics and thus must resort to estimating the array correlation matrix ($\bar{R}_{xx}$) and the signal correlation vector ($\bar{r}$) over a range of snapshots or for each instant in time.

The instantaneous estimates of these values are given as

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

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

We can employ an iterative technique called the method of steepest descent to approximate the gradient of the cost function. The direction of steepest descent is in the opposite direction as the gradient vector. The method of steepest descent can be approximated in terms of the weights using the LMS method. The steepest descent iterative approximation is given as

$$\bar{w}(k+1) = \bar{w}(k) - 1/2\mu\,\nabla_{\bar{w}}(J(\bar{w}(k)))$$

where, μ is the step-size parameter and $\nabla_{\bar{w}}$ is the gradient of the performance surface. If we substitute the instantaneous correlation approximations, we have the LMS solution.

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

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

Where

$$e(k) = d(k) - \bar{w}^H(k)\,\bar{x}(k) = \mathit{error\ signal}$$

The convergence of the LMS algorithm in above equation is directly proportional to the step-size parameter μ. If the step-size is too small, the convergence is slow and we will have the overdamped case. If the convergence is slower than the changing angles of arrival, it is possible that the adaptive array cannot acquire the signal of interest fast enough to track the changing signal. If the step-size is too large, the LMS algorithm will overshoot the optimum weights of interest. This is called the underdamped case. If attempted convergence is too fast, the weights will oscillate about the optimum weights but will not accurately track the solution desired. It is therefore imperative to choose a step-size in a range that insures convergence. It can be shown that stability is insured provided that the following condition is met.

$$0 \leq \mu \leq 1/2\lambda_{\max}$$

where $\lambda_{\max}$ is the largest eigenvalue of $\hat{R}_{xx}$. Since the correlation matrix is positive definite, all eigenvalues are positive.

CHAPTER 6

6. RESULTS AND DISCUSSIONS

6.1 Fixed Beamforming

The algorithm of maximizing signal-to-interference ratio with including noise variance is implemented on MATLAB platform, the different parameters are varied to get the following results. In the following results we have included one desired signal and two undesired signals which have to be nullified through the algorithm so that beamforming can be achieved in the direction of desired signal.

The following are the different parameters that can be varied to get the results:

6.1.1 Parameters:

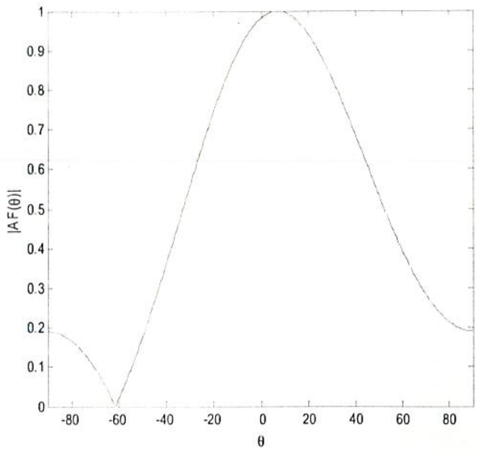
Separation distance between elements (d)
Noise Variance (sig2)
The Number of Array Elements (N)
The angle of the desired signal (th00)
The angle of first undesired signal (th10)
The angle of the second undesired signal (th20)

6.1.2 Parameter Varied:-

The Number of Array Elements (N)

The remaining parameters are:

d = 0.5, sig2 = 0.001, th00 = 10 °, th10 = 60 °, th20 = -40 °



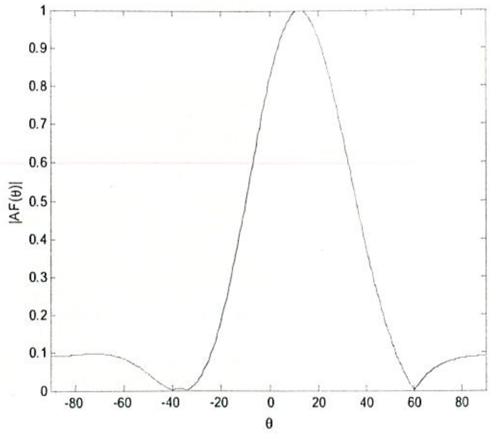
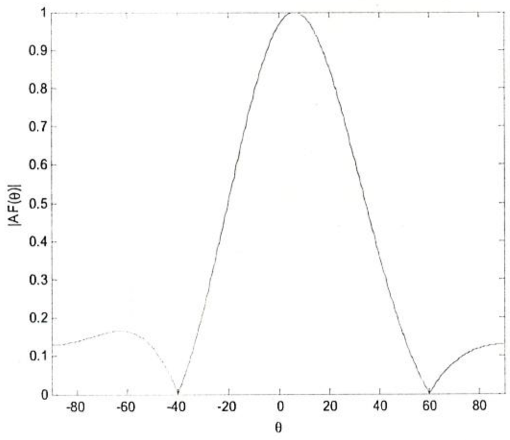


Fig 6.3 Array factor plot(N=4)

Fig 6.1 Array factor plot(N=2)



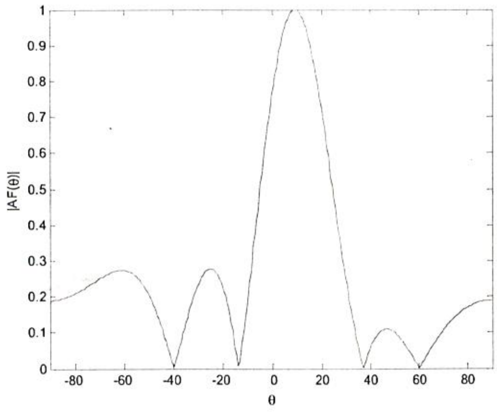


Fig 6.4 Array factor plot(N=5)

Fig 6.2 Array factor plot(N=3)

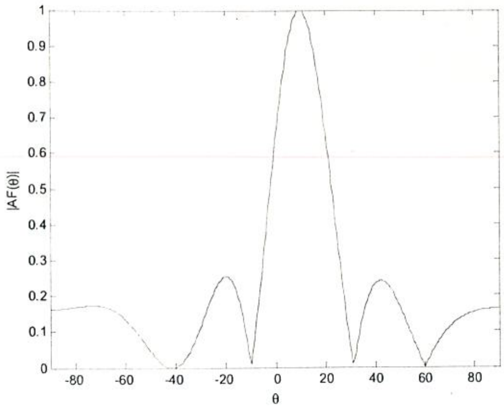


Fig 6.5 Array factor plot(N=6)

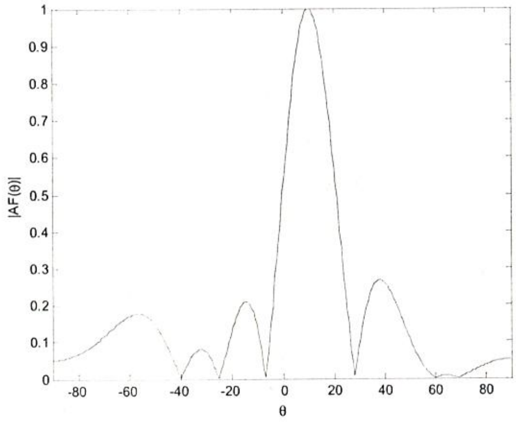


Fig 6.6 Array factor plot(N=7)

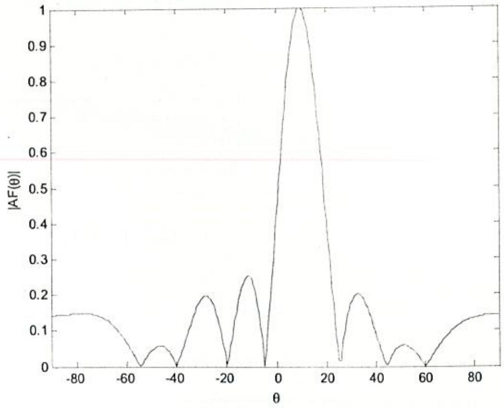


Fig 6.7 Array factor plot(N=8)

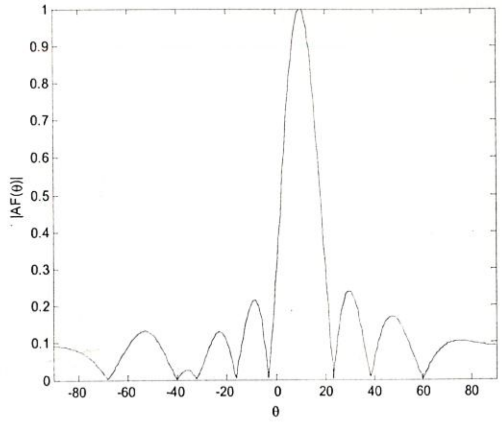


Fig 6.8 Array factor plot(N=9)

6.1.2.1 Discussion:

Thus we can see from the results obtained as the number of elements increases our beam becomes more defined and accurate beamforming is achieved, but at the same time by increasing the number of elements the no of lobes get increased signifying for the respective element and cost of putting up of the array gets increased since new elements gets added.

6.1.3 Parameter Varied:-

The angles of the desired and undesired signals (th00, th10, th20)
The remaining parameters are :
d = 0.5 , sig2 = 0.001, N=5

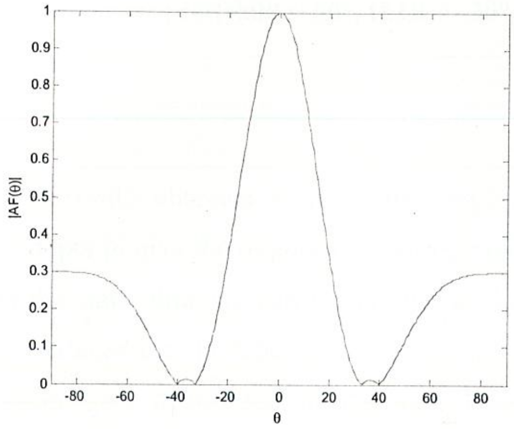


Fig 6.9 Array factor plot(th00 = 0°, th10 = -40°, th20 = 40°)

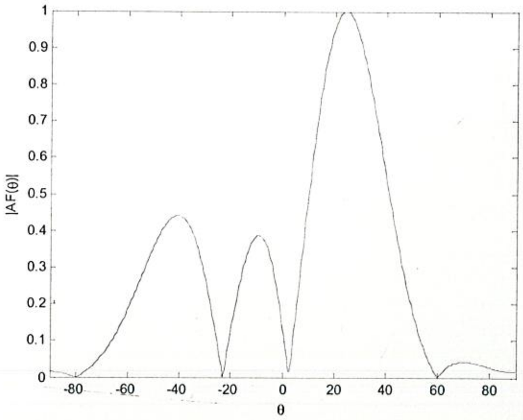


Fig 6.10 Array factor plot(th00 = 30°, th10 = -80°, th20 = 60°)

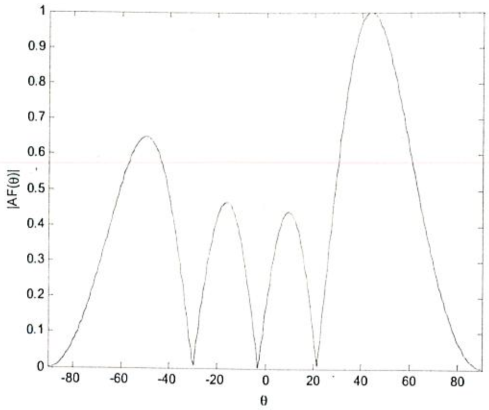


Fig 6.11 Array factor plot(th00 = 60°, th10 = -30°, th20 = 90°)

6.1.3.1 Discussion:

Thus we can see from the results obtained as the desired angles and undesired angles is changed the algorithm adopts to give the required output by nullifying the array factor in undesired direction. At the same time we can notice that as the difference between the desired and undesired is reduced the sidelobes get much higher leading to inefficiency as now much of the power gets distributed in the side lobes also apart from just concentrating on the desired direction

6.1.4 Parameter Varied:-

Noise Variance (sig2)

The remaining parameters are :

d = 0.5 , th00 = 10 °, th10 = 60 °, th20 = -40 °, N=5

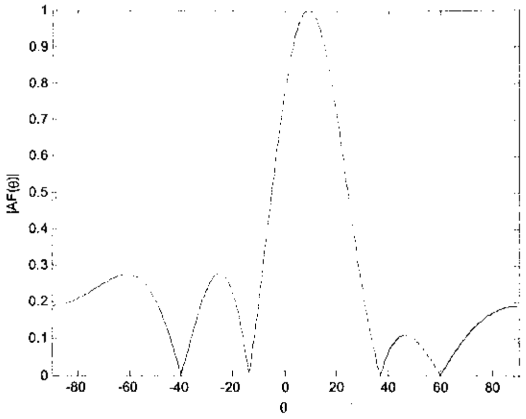


Fig 6.12 Array factor plot (sig2 = .001)

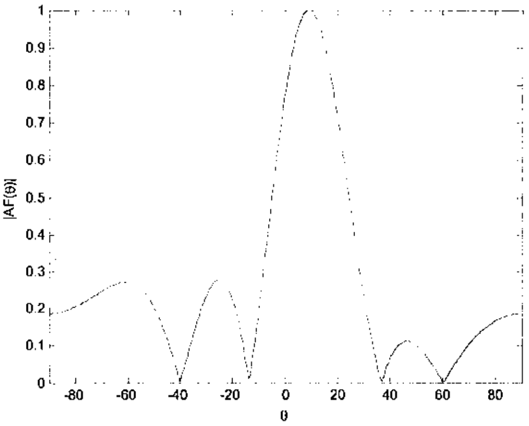


Fig 6.13 Array factor plot (sig2 = .1)

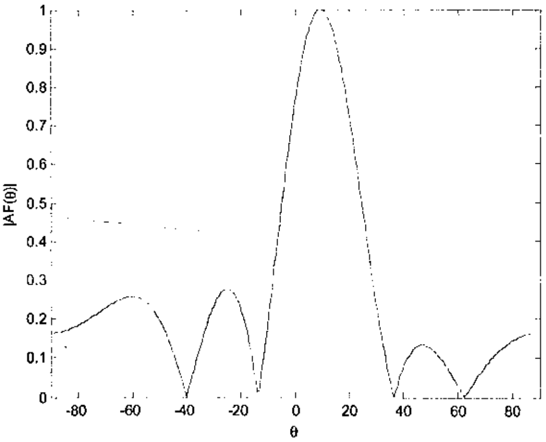


Fig 6.14 Array factor plot (sig2 = 1)

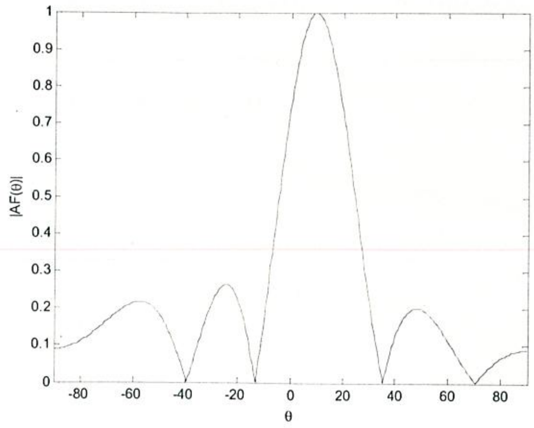


Fig 6.15 Array factor plot (sig2 = 10)

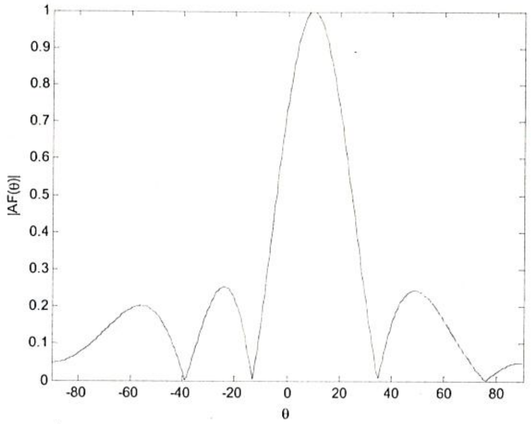


Fig 6.16 Array factor plot (sig2 = 100)

6.1.4.1 Discussion:

Thus we can see from the results obtained as the noise variance is increased the efficiency of beamforming gets reduced i.e. nulls gets shifted from -40° and 60°, also sidelobes get changed.

6.2 Adaptive Beamforming

For adaptive beamforming LMS (least mean square) method is implemented on MATLAB platform, the different parameters are varied to get the results. In the following results we have included one desired signal and one undesired signal which have to be nullified through the algorithm so that beamforming can be achieved in the direction of desired signal.

In this method we are showing three results for variation in each parameter, one is the plot for array factor, second is the plot showing the desired signal and array output vs iteration no. and third is the plot for mean square error vs iteration no.

The following are the different parameters that can be varied to get the results:

6.2.1 Parameters:

Separation distance between elements (d)

The Number of Array Elements (N)

The angle of the desired signal (thetaS)

The angle of undesired signal (thetaI)

Number of iterations (a)

Step size (mu)

6.2.2 Parameter Varied :–

Number of Elements

Rest parameters are

d = 0.5, thetaS = 10, thetaI = 60, a = 100, mu = 0.01

Number of Elements-2

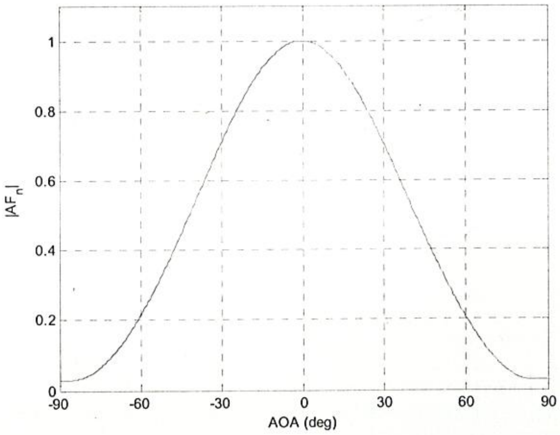


Fig 6.17 Array factor plot

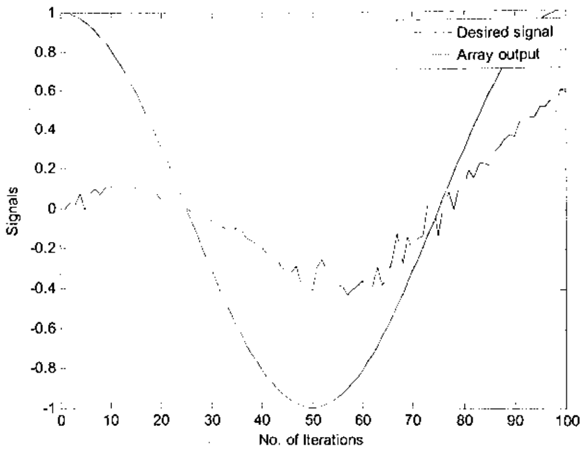


Fig 6.18 Array output plot

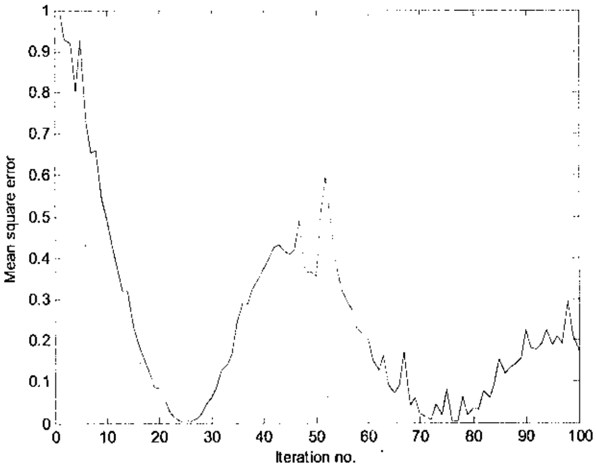


Fig 6.19 mean square error vs iteration plot

Number of Elements-5

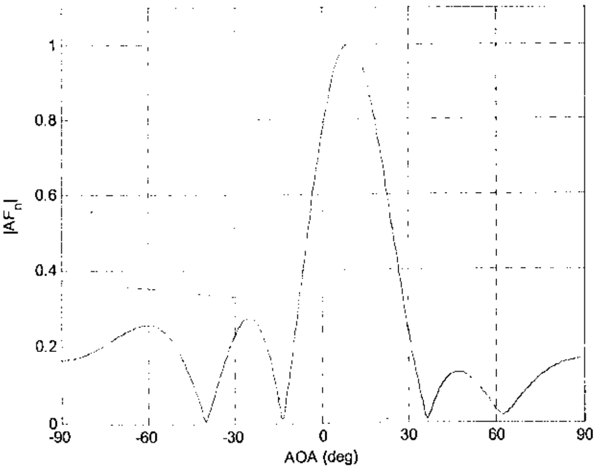


Fig 6.20 Array factor plot

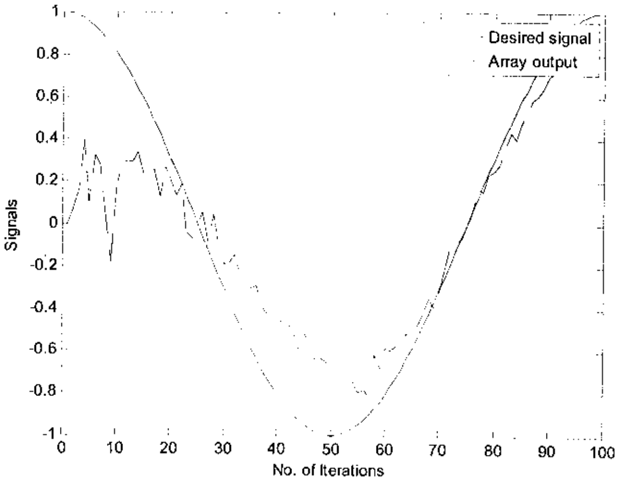


Fig 6.21 Array output plot

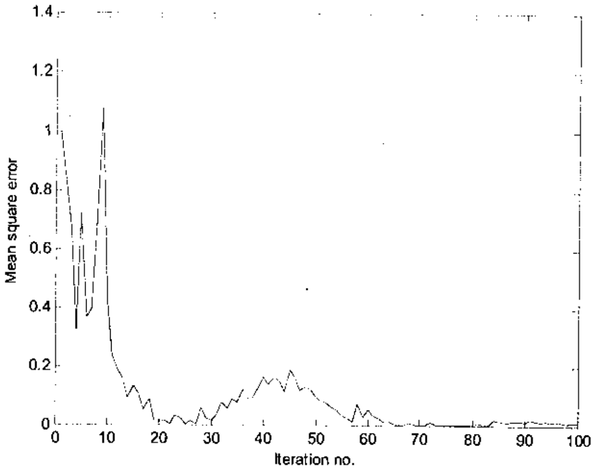


Fig 6.22 mean square error vs iteration plot

Number of Elements-7

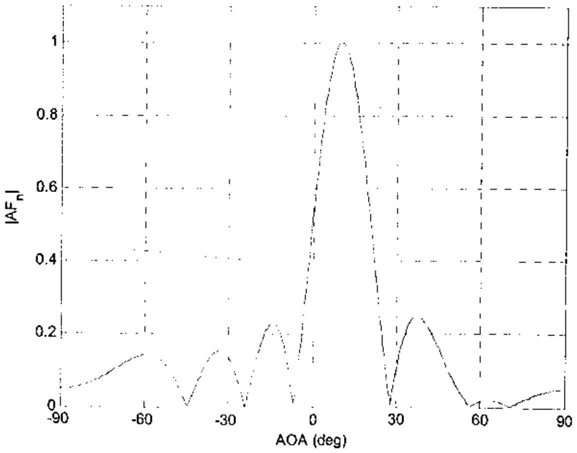


Fig 6.23 Array factor plot

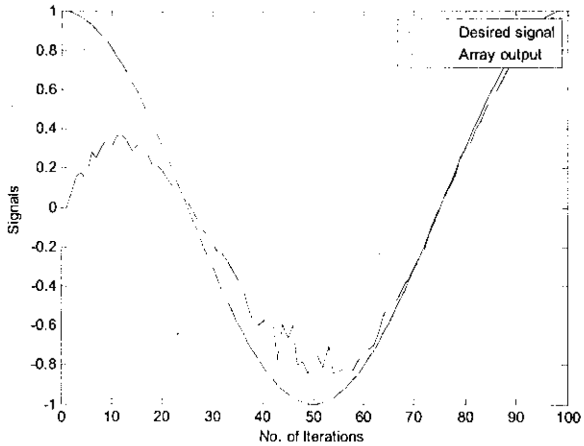


Fig 6.24 Array output plot

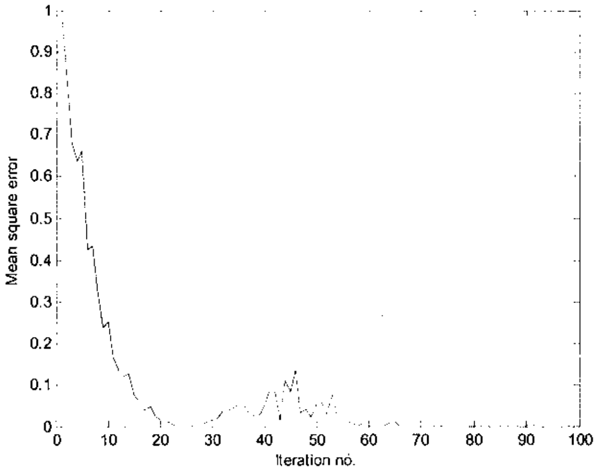


Fig 6.25 mean square error vs iteration plot

Number of Elements-10

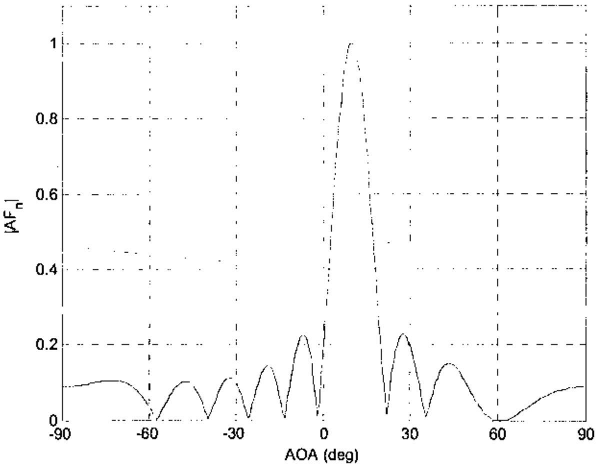


Fig 6.26 Array factor plot

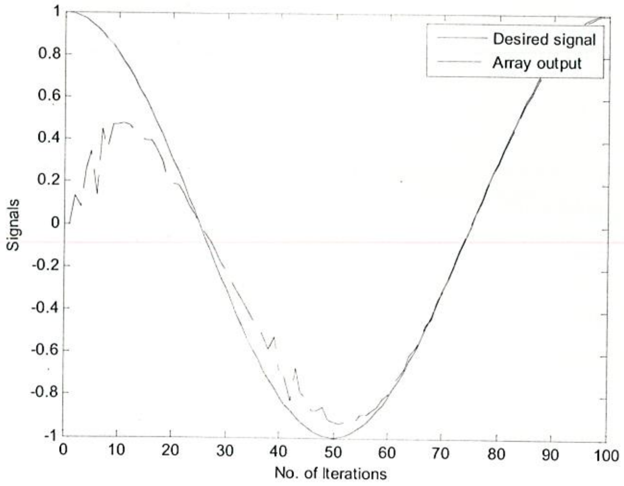


Fig 6.27 Array output plot

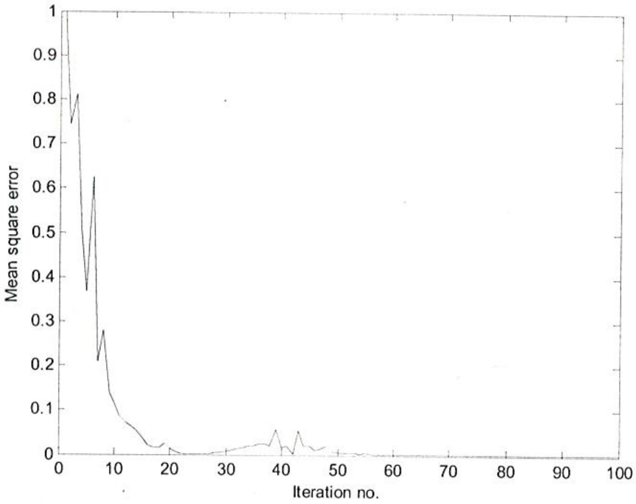


Fig 6.28 mean square error vs iteration plot

6.2.2.1 Discussion:

Thus we can see from the results obtained as number of elements are increased the efficiency increases because mean square error reduces. This is happening because the array output started following the desired signal in lesser number of iterations than it was following when the number of elements are lower.

6.2.3 Parameter Varied :–

Step Size

Rest parameters are

d = 0.5, thetaS = 10, thetaI = 60, a = 100, N = 5

Step Size = 0.01

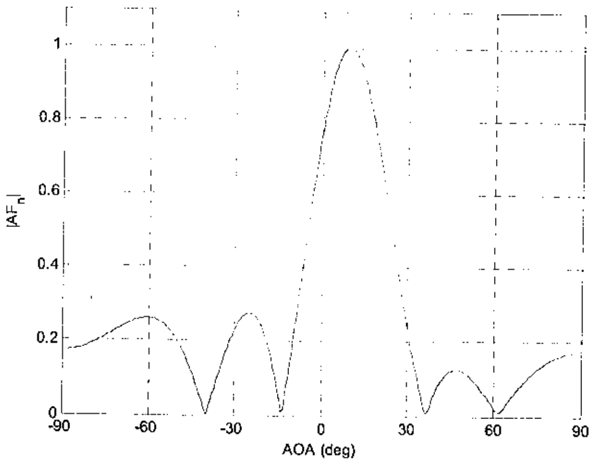


Fig 6.29 Array factor plot

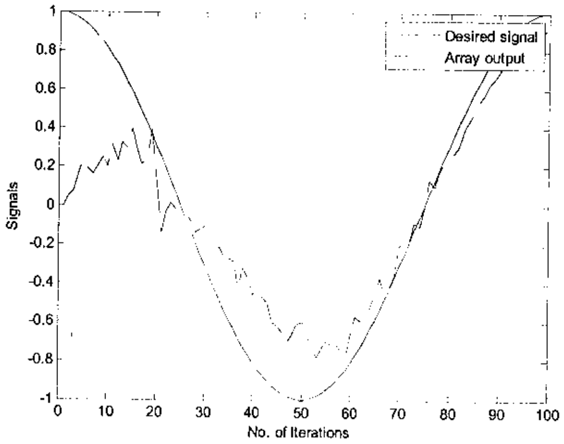


Fig 6.30 Array output plot

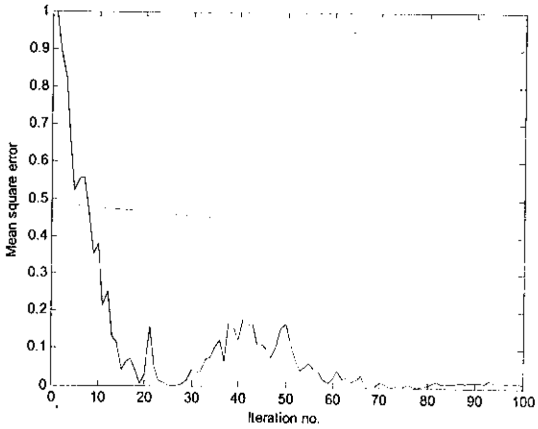


Fig 6.31 mean square error vs iteration plot

Step Size = .02

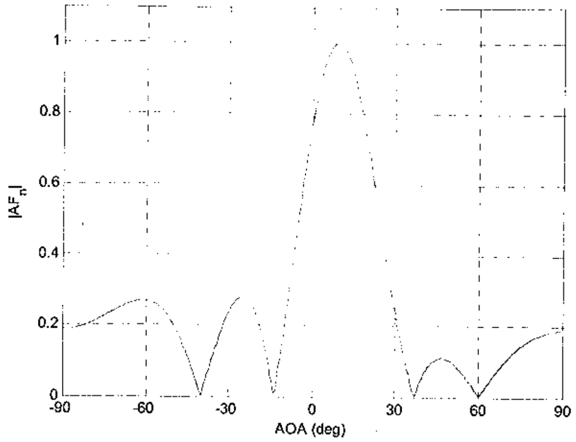


Fig 6.32 Array factor plot

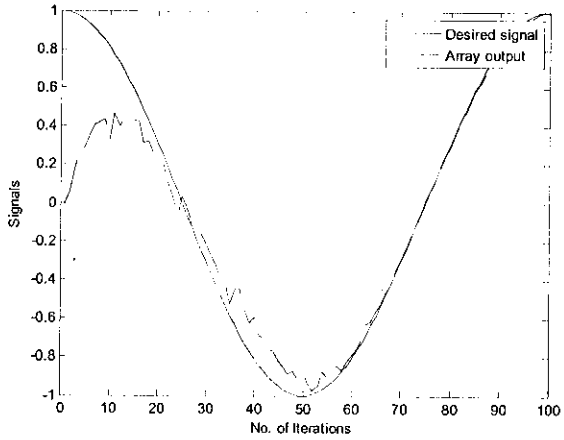


Fig 6.33 Array output plot

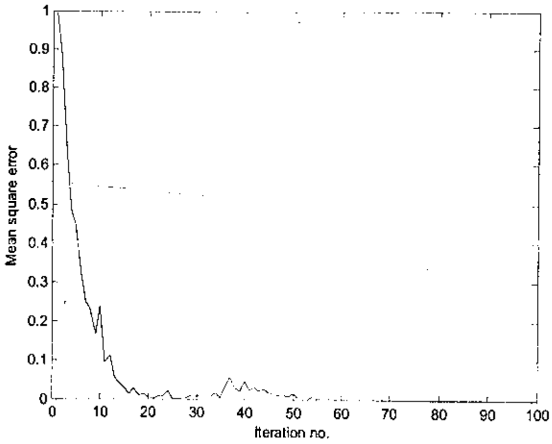


Fig 6.34 mean square error vs iteration plot

Step Size = .04

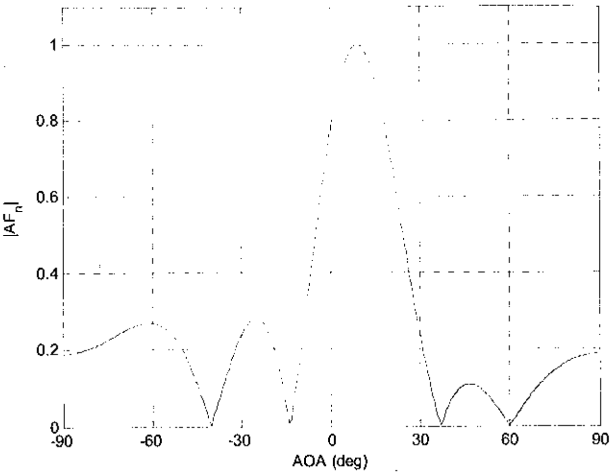


Fig 6.35 Array factor plot

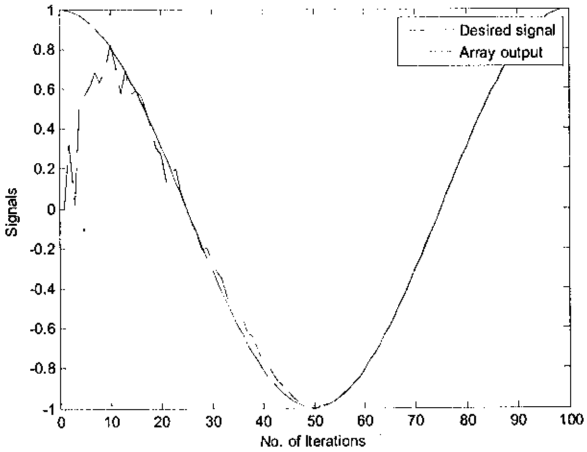


Fig 6.36 Array output plot

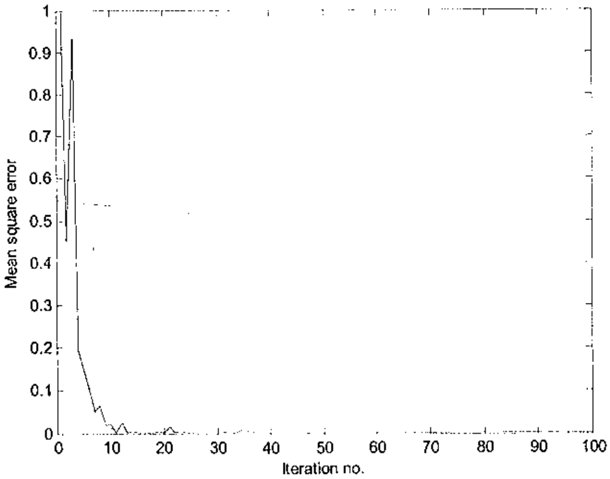


Fig 6.37 mean square error vs iteration plot

Step Size = .06

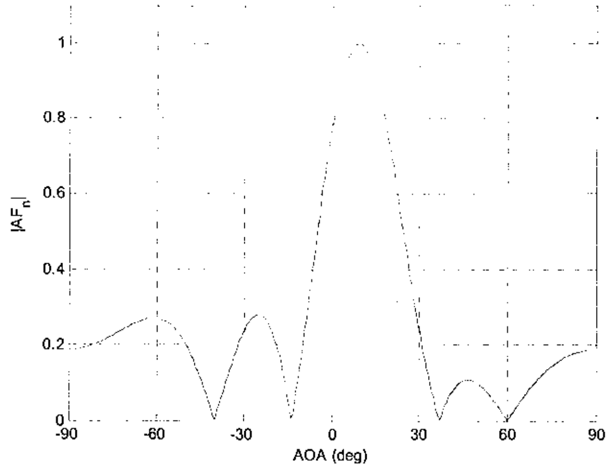


Fig 6.38 Array factor plot

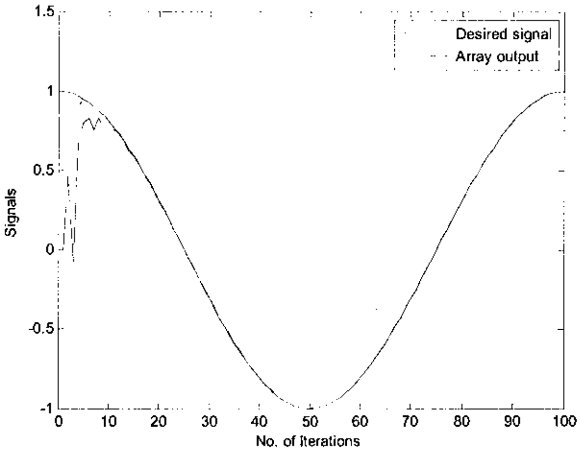


Fig 6.39 Array output plot

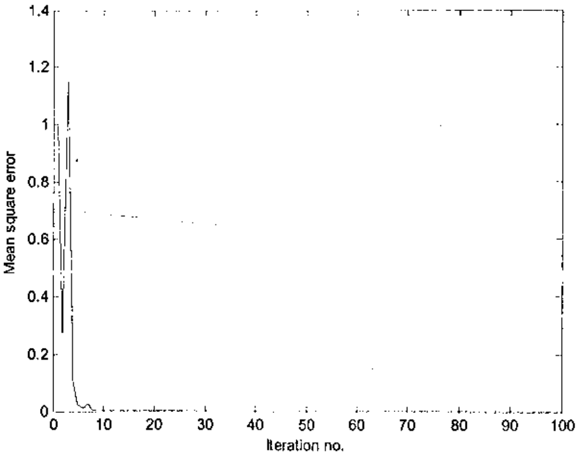


Fig 6.40 mean square error vs iteration plot

6.2.3.1 Discussion:

Thus we can see from the results obtained as step size is increased the error gets reduced, this is so because the convergence of the LMS algorithm is directly proportional to step size parameter mu. But if the step size is too large, LMS algorithm will overshoot the optimum weights of interest.

Conclusion and Scope For Future Work

Smart antennas vastly improve the efficiency of wireless transmission and are likely to become the standard in use for connections between wireless devices. As the technology becomes cheaper it is likely that all devices will utilise smart antennas. This transition could be compared to the use of hubs in wired computer networks and there replacement with switching technology as the costs of implementation reduced.

In conclusion to this project "Smart Antennas and Beamforming", these antenna systems are the antennas with intelligence and the radiation pattern can be varied without being mechanically changed. With appropriate switched and adaptive algorithms such as maximizing SIR, Least mean square (LMS) approach the beam forming can be obtained. As the system uses a DSP processor the signals can be processed digitally and the performance is with a high data rate transmission and good reduction of mutual signal interference. In this project, we implemented fixed and adaptive beamforming algorithms and analysed the results.

Research into smart antenna technologies has increased tremendously to keep pace with the constantly expanding needs of the wireless communications industry. Emerging application areas such as ultra wideband (UWB), radio frequency identification (RFID), and mobile direct broadcast satellite (DBS) are expected to see extensive adoption of these technologies in the next few years. For instance, smart antennas can greatly improve the performance of mobile DBS in increasingly popular automotive accessories such as back-seat video systems. Innovative applications based on the benefits of these technologies, such as providing location information during emergencies, are also emerging in the market. Exploitation of beamforming for other functions such as routing. An example is the use of directional antennas to reduce the query flooding overhead, and simultaneously shorten the average hop-count of routes in a reactive protocol.

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Webpages:

www.wikipedia.com

Appendix

SOURCE CODES:

1. Maximum Signal to interference ratio

```
d=input ('The Separation Distance Between Elements : ') ;
N=input ('The Number of Array Elements : ') ;
theta=-pi/2:.01:pi/2;
ang=theta*180/pi;
th00=input ('The angle of the desired signal : ') ;
th10=input ('The angle of first undesired signal : ') ;
th20=input ('The angle of the second undesired signal : ') ;

th0=th00*pi/180;      % receive angle
th1=th10*pi/180;        % first interferer angle
th2=th20*pi/180;         % second interferer angle
s=1;              %signal amplitude
n=1:N;
a=exp(1j*2*pi*(n-2)*d*sin(th0))';     % received angle steering vector
Rss=a*a';
 n1=exp(1j*2*pi*(n-2)*d*sin(th1))';     % interferer 1 steering vector
n2=exp(1j*2*pi*(n-2)*d*sin(th2))';     % interferer 2 steering vector
 A=[n1 n2];
Rii=A*A';             % interferer correlation matrix
Ruu=Rii ;             % total undesired signal correlation matrix
R=inv(Ruu)*Rss;
[Ev,v]=eig(R);         % calculate eigenvalues and eigenvectors
[Y,Index]=sort(diag(v));  % sorts the eigenvalues from least to greatest
SIRmax=max(Y);           % find maximum SIR
w=inv(Ruu)*a/SIRmax;      % normalize weight vector
for j=1:length(theta)
   th=theta(j);
   aa=exp(1j*2*pi*(n-2)*d*sin(th))';
   y(j)=w'*aa;
```

```
end
figure;
plot(ang,abs(y)/max(abs(y)),'k')
axis([-90 90 0 1])
xlabel('\theta')
ylabel('|AF(\theta)|')
```

2 : Adding Gaussian white noise :

```
d=input ('The Separation Distance Between Elements : ') ;
N=input ('The Number of Array Elements : ') ;
sig2=input ('noise variance ? : ') ;
theta=-pi/2:.01:pi/2;
ang=theta*180/pi;
th00=input ('The angle of the desired signal : ') ;
th10=input ('The angle of first undesired signal : ') ;
th20=input ('The angle of the second undesired signal : ') ;

th0=th00*pi/180;     % receive angle
th1=th10*pi/180;       % first interferer angle
th2=th20*pi/180;       % second interferer angle
s=1;           %signal amplitude
n=1:N;
a=exp(1j*2*pi*(n-2)*d*sin(th0))';     % received angle steering vector
Rss=a*a';
n1=exp(1j*2*pi*(n-2)*d*sin(th1))';    % interferer 1 steering vector
n2=exp(1j*2*pi*(n-2)*d*sin(th2))';    % interferer 2 steering vector
A=[n1 n2];
Rnn=sig2*eye(N);      % noise correlation matrix
Rii=A*A';          % interferer correlation matrix
Ruu=Rii+Rnn;        % total undesired signal correlation matrix
R=inv(Ruu)*Rss;
[Ev,v]=eig(R);        % calculate eigenvalues and eigenvectors
[Y,Index]=sort(diag(v)); % sorts the eigenvalues from least to greatest
SIRmax=max(Y);          % find maximum SIR
w=inv(Ruu)*a/SIRmax;      % normalize weight vector
for j=1:length(theta)
  th=theta(j);
  aa=exp(1j*2*pi*(n-2)*d*sin(th))';
  y(j)=w'*aa;
```

```
end
figure;
plot(ang,abs(y)/max(abs(y)),'k')
axis([-90 90 0 1])
xlabel('\theta')
ylabel('|AF(\theta)|')
```

3 : Least Mean Square Approach :

```
d=input ('The Separation Distance Between Elements : ') ;
N = input('   How many element do you want in uniform linear array?   ');   % number of elements in array
thetaS = input('   What is the desired users AOA (in degrees)?   ');
thetaI = input('   What is the interferers AOA(in degrees)?   ');
%----- Desired Signal & Interferer -----%
T=1;
t=(1:100)*T/100;
a= input('no. of iterations ?');
it=1:a;
S=cos(2*pi*t/T);
thetaS = thetaS*pi/180;              % desired user AOA
I = randn(1,100);
thetaI = thetaI*pi/180;              % interferer AOA
%----- Create Array Factors for each user's signal for linear array -----%

vS = []; vI = [];
i=1:N;
vS=exp(1j*(i-1)*2*pi*d*sin(thetaS)).';
vI=exp(1j*(i-1)*2*pi*d*sin(thetaI)).';

%----- Solve for Weights using LMS -----%

w = zeros(N,1);
 X=(vS+vI);
Rx=X*X';
%mu=1/(4*real(trace(Rx)))
mu = input('What is step size?') ;
wi=zeros(N,max(it));
for n = 1:length(S)
   x = S(n)*vS + I(n)*vI;
```

```
    %y = w*x.';
    y=w'*x;

    e = conj(S(n)) - y;     esave(n) = abs(e)^2;
 %    w = w +mu*e*conj(x);
    w=w+mu*conj(e)*x;
    wi(:,n)=w;
    yy(n)=y;
 end
 w = (w./w(1));   % normalize results to first weight
 %----- Plot Results -----%
 theta = -pi/2:.01:pi/2;
 AF = zeros(1,length(theta));

 % Determine the array factor for linear array
 for i = 1:N
   AF = AF + w(i)'.*exp(1j*(i-1)*2*pi*d*sin(theta));
 end
 figure
 plot(theta*180/pi,abs(AF)/max(abs(AF)),'k')
 xlabel('AOA (deg)')
 ylabel('|AF_n|')
 axis([-90 90 0 1.1])
 set(gca,'xtick',[-90 -60 -30 0 30 60 90])
 grid on
 figure;
 plot(it,S,'k',it,yy,'k--')
 xlabel('No. of Iterations')
 ylabel('Signals')
 legend('Desired signal','Array output')
 figure;plot(it,esave,'k')
 xlabel('Iteration no.')
 ylabel('Mean square error')
```