# BEAM FORMING AND ANGLE OF ARRIVAL IN ANTENNA ARRAY JAMMING

**A Dissertation**

**Submitted in partial fulfillment of the requirement for the award of the degree of**

**Master of Technology**
**in**

**Electronics and Communication Engineering**

(With Specialization in RF and Microwave Engineering)

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# CANDIDATE'S DECLARATION

I hereby declared that the work carried out for the dissertation by topic name, ***"Beam Forming And Angle Of Arrival In Jamming",*** which has been acceded in the partial fulfilment of the obligations for the award of degree of ***Master of Technology in RF & Microwave Engineering*** submitted in the Department of Electronics and Computer Engineering, **Indian Institute of Technology**, Roorkee (INDIA), is an original report of my own work accomplished under the guidance of **Dr. R. K. Panigrahi**, Associate Professor, Department of Electronics and Computer Engineering, Indian Institute of Technology, Roorkee.

I have not acceded the details present in this dissertation for any other academic/professional degree or diploma.

**Date** : June 2019 **(Jitendra Rawat)**

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# SUPERVISOR'S DECLARATION

This is to approve that this work entitled, "***Beam Forming And Angle Of Arrival In Antenna Arrays Jamming*",** which has been put up by Jitendra Rawat in this document is his own work, accomplished by him under my supervision. I also certify that the above statement written by the candidate is correct to the best of my knowledge and belief.

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# ABSTRACT

In the recent times, there have been diversified upsurge in the technology of RF receivers. The formation of accurate beam is a compelling facet of performance in radar and communication systems increased flexibility. The digital component of the beam forming is called Digital Beam forming (DBF), where it utilises a Digital mechanics for the forming of a beam. Cancellation of the jammer signal presence is a step for which a DBF is heavily relied upon. The pivotal competence of Digital beam forming is to sample and digitise the incident signal accurately which is incident on the aperture of the antenna. This thesis examines the design concepts of an antenna array and also the aspects of determining Angle of Arrival (AOA) associated in the radar systems.

The evaluation of the approaching dispensation for a source is of prominence in Non-Comm field. In past few years, research on appropriate DoA estimation techniques has been a prime area for communication engineers. The field of data structure set of analysing and modifying signal can be categorised into self adaption signal analysing and energy spread in space. The distribution pattern of frequency in space domain exhibits the distribution in the complete hemisphere. In receiving mode, processing of the signal by digital means leads to formation of the beam known as signal processing of the array which gives the radar a flexibility to design/form a particular pattern of beam. The process of regulating beam forming process is done by providing corrective action on to the array weights as variations in the feed system, the antenna and the receiver channel in real time and simultaneously facilitating flexible control in formation of the beam pattern. The existence of jammer in the area of exercise is invalidated, leading to better output performance of the antenna assembly.

# ACRONYMS

| | |
|---|---|
| AoA | Angle of Arrival |
| DoA | Direction of Arrival |
| SoI | Signal of Interest |
| MAI | Multiple Access Interference |
| SeIR | Signal to Interference Ratio |
| SBS | Switched Beam System |
| MUSIC | Multiple Signal Classification |
| MVDR | Minimum Variance Distortion less Response |
| LP | Linear Prediction |
| SLL | Side Lobe Level |
| HPBW | Half Power Beam Width |
| MLP | Multi Layer Perception |
| RMSE | Root Mean Square Error |

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# CHAPTER- 1

# 1. Introduction

## 1.1 Motivation and Scope

Adaptive beam forming and Angle of Arrival are the topics of acute interest for delving in radar and communication applications in the present times. The fundamental significance for the cause is the ability to cardinally generate the nulls and impose on to the interfering sources, thereby constricting noise disposition and augment the detection of desired signals. The antenna array with adaptive capabilities has an array set up, an adaptive processor exerting in real time. This adaptive processor gives out beam steering command, simultaneously sampling the current location. Subsequently it optimises the weight vectors and selects a suitable algorithm as per command to generate an optimum output.

Direction of Arrival (DoA) connotes the general line of direction of an incoming signal which in turn refers to the location of the source emanating the signal. With the help of sensors, various wave specifications which form part of DoA estimation can be extracted such as frequency, angle and time difference of the source under consideration. Frequently, in the literature the terms DoA and AoA would be interchanging used. DoA estimation is an important parameter in various engineering applications such as sound signal processing, track and scan, finding friend and foe in the hostile military environment etc.

The technique of beam forming is the result of the related technique of DoA estimation. The radiation pattern of the antenna array is formed as a process of beam forming and is the result of constructive addition of signal phases of targets and simultaneously cancellation of interferers. Thus, the direction of the signal affecting on an antenna array is a very meaningful aspect in the area of beam forming. Compared to the techniques involving spatial modulation, beam forming is conventional choice in terms of complexity. In order to track/locate a particular target, direction finding algorithms are used to detect the position of the mobile users as they move within or between cells. DoA estimation loops can be used to find the location of an enemy aircraft in the hostile environment.

Large numbers of signals from different sources are subjected to the array system. These impinging signals have random direction and random amplitude and are also accompanied with noise, making estimation a complex process. However, the most approved techniques are super resolution algorithms, Bartletts, MVDR, Multiple Signal Classification(MUSIC), Estimation of Signal Parameters via Rotational Invariance Techniques (ESPRIT) and their further adapted types (e.g. Root MUSIC)[1]-[4], which uses snapshots of uncorrelated signals. Some faster algorithms are also studied which use less number of signal snapshots. In these methods, DoA is calculated by drawing the spatial spectrum $P(\theta)$, the mean power credited by an array as a function of $\theta$, and subsequently administering the local maxima of this computed spectrum.

One of the techniques to examine the beam forming and beam steering is by using Butler Matrix [3] that can be executed on an antenna array. The use of the Butler Matrix leads to improved signal to clutter ratio and frequency reuse. Butler matrix makes use of delay lines and phase shifters for improved beam response. It computes the frequency domain representation in space for $2^n$ orthogonal beams. The excitation provided as input is controlled in phase and amplitude by the network. At lower frequencies bands, the size of the branch-line coupler is inversely proportional. The Butler Matrix mode of beam forming overcomes this problem of increased size of the branch line coupler and also has a significant reduced circuitry complexity.

## 1.2 Beam Forming

The radar takes the spatial dispensation of reflectivity in the three-dimensional spherical coordinates system of range, horizontal plane angle and vertical plane angle. Scores of radars process the signals in domains related to Fourier transform of either slow-time (pulse number) or, in case of antenna array, received channels. These spectral domains correlate to Doppler shift and angle of arrival, respectively and represent the fourth and fifth potential dimensions of a radar signal.

Beam forming is a process of calculation in space domain where, the weight can be selected for channeling the array signal from relevant direction and hindering from other directions after pre determined analog and digital processing. In time domain the matched filter relates energy and time, obtaining a particular gain response in a specified direction while attenuating in other for the antenna. Beam forming is the latest topic to be frequently used in the military applications such as surveillance and hostile target tracking.

The conventional analog process of beam forming was a complex and an expensive process and was also precarious to component strengths and drifts. The principle of time delay and phase shift is the basis of beamforming in analog and digital beam forming techniques.

The time delay generation is a ambitious process and is therefore restricted in use and is brought process on need as in case of more array elements and in case of wide band. In the phase shifting process, a phase value is imported in place of time delay for each receiver. Such a set up works in narrow band  and systems with less number of array elements even though it is easier to implement It is elementary to introduce such a abetment but it works resultantly only with narrow band systems and/or small arrays. The affiliation of normalized gain with bandwidth and delay (distinctive time of striking of the wave front on to the antenna elements due to the layout pattern) is as follows(normalized to 1):

$$G = \frac{\sin(\pi B \Delta t)}{\pi B \Delta t} \quad (1)$$

The uniformly spaced array (LES) must be linear array and must be contemplated as ideal disposition for a basic beam forming employment.  LES is the space dimensional form of a time related Finite Impulse Response (FIR) filter. As shown in Fig 1.1, it is seen that as per angle of incidence α and the reference element, there is a time variation at each antenna element for the wave front to arrive. The time variation for every antenna element of the antenna set up is given by:

$$\Delta t = \frac{(n-1) d \sin \alpha}{c}$$

Where "c" denotes the speed of light and "d" depicts the element spacing

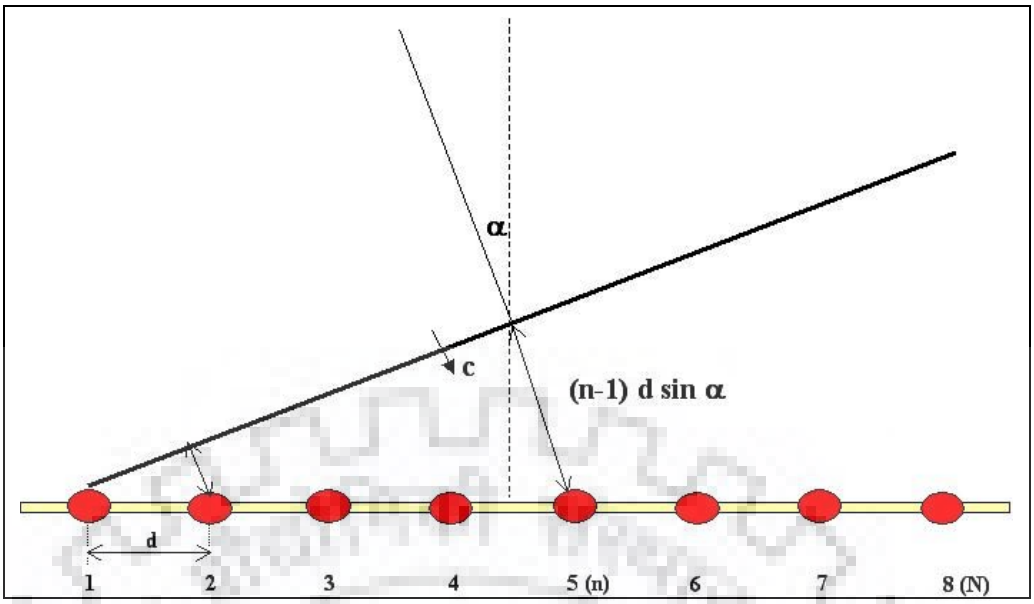



**Fig.1.1. Linear Equally Spaced Array**

The time impediment calculated above when subjected to individual elements, the array can be moved in a pre-determined line of sight, while with the help of amplitude controlling variables, we can curb the side lobes and null steering can be achieved for radio intervention rejection. A beamformer having N elements can lead the array in a obligatory direction and can simultaneously reject N-1 interrupting sources arriving from N directions. With this analogy the array is similar to a matched filter in space domain with the weights acting as the filter coefficients. On applying frequency transform property on to the amplitude coefficients, the pattern of radiations obtained is given by the expression:

$$S(\alpha) = \sum_{n=0}^{N-1} W_n e^{j(\xi n d \sin\alpha)} \tag{3}$$

Where ξ=2π/λ (rad/m) and λ (m) represents the wavelength. When all the elements are matched in similar weight values, we get the side lobes at -13 dB. With more accurate calculations of weight values, we can get side lobe levels to –20 /-25 dB.

In the above figure, the first element is considered to have zero phase in respect to the incoming signal. The signal at the nth element leads/lags with in phase ξ n d sinα. The phase delay vector encompasses the information of the approaching direction of the signals:

$$\nu = \left[1 \ e^{j\xi d \sin\alpha} \ldots\ldots\ldots\ldots \ e^{j(N-1)\xi d \sin\alpha}\right] \tag{4}$$

The array factor is defined as:

$$F(\xi, \alpha) = W^T \nu$$

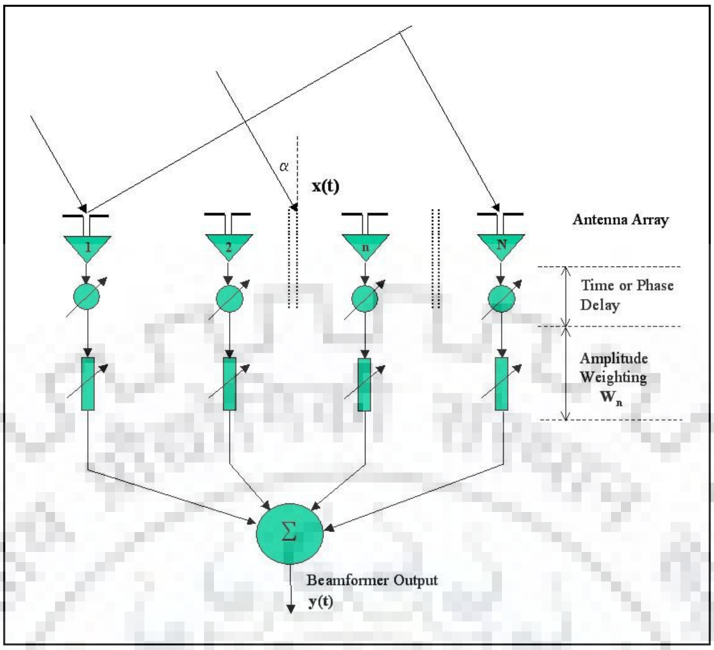



**Fig.1.2. RF Level Basic Beamformer Block Diagram**

Let the value of $\xi$ and d be fixed.

The weight vector definition is given by the expression:

$$W_n = e^{jn\alpha} \tag{5}$$

Let the wave front at the antenna elements are at an angle $\varphi_0$. In order to have maximum retort in the direction of the wave front, the phase of the complex weight must be

$$\alpha = d \sin \phi_0 \tag{6}$$

Fig 2 highlights the basic block diagram of a digital beamformer. The incoming RF signal is frequency converted to intermediate value followed by digitization at a correct Nyquist frequency. A down converting device (DDC), accomplishes the band conversion of the signal and the external CPU calculates and accordingly adjusts the weighing vector and depends on the direction of progress. The operational band of frequencies of this set up is restrained operational speed of the digital devices. The size of the array commands the calculation of time delay followed by calculation of phase delay as last step.

## 1.3 Adaptive Beam Forming

Phased array antennas have many employments and were an ambitious advancement in the field of multifunction radars. Scanning with the help of a beam attained a major breakthrough in beam agility and many simultaneous tasks like track and scan could be performed on multiple targets. The pay offs of DBF is obtained at the risk of needing increased number of transreciever and large computational throughputs to achieve digital operations that were formerly done with analog hardware. As the antenna receives a signal, the beam former weights are accordingly varied by the Adaptive algorithms using pre fed conditions to enhance the signal power and leading to detection. This concedes the signal info which are not required and the enhancing the gain.

**Key Points:-**

(a) DBF augments Phased array antenna performance.

(b) Single Element DBF is often speculative for complex array assembly operating at high frequencies.

(c) The sub array in DBF curtails the receiver count for easier operation.

(d) The sub array architecture majorly affects the performance due to the maxima and minima.

(e) The spatial channel controls the ADBF measurements.

(f) The operational range in time and space are enhanced by ADBF by using computational conditions.

(g) The operational range in space can be used in adaptive cancellation in jamming environment.

### 1.3.1 Digital Beam Forming Fundamentals

The signals from individual antenna elements are added through a radio frequency (RF) combiner networks made up of one or more stages of phase shifters, attenuators, amplifiers and time delay units. The beams are formed in analog channel of the system and followed by use of analog-to-digital converters for obtaining digital signals which are in turn fed to the signal and data processing computers for further processing.

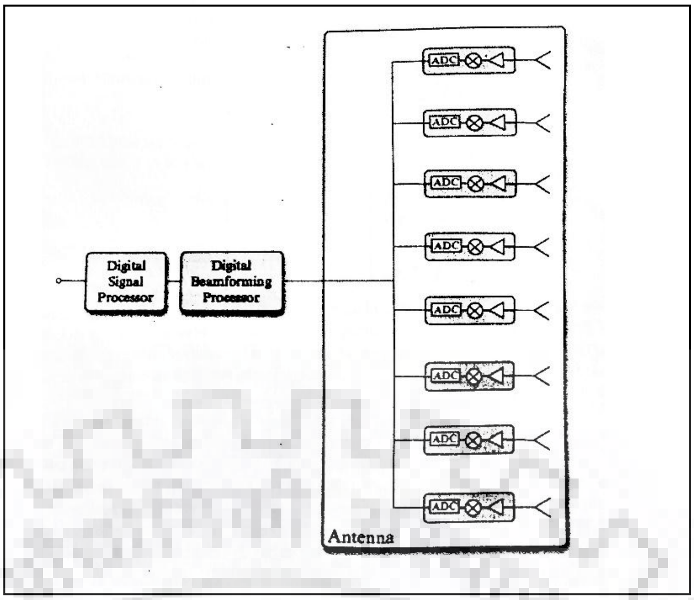



**Fig. 1.3. Element-Level Digital Beamforming**

The above is the receiver block showing each block in DBF. In the receive mode the signal passes through the LNA and is then fed to the receiver where it is converted to digital signal both in I and Q phase samples. The digital I/Q samples are then forwarded to the processor. The digital I/Q samples are then sent to a digital beam forming processor where the beam forming is done in the computer.

The beam former can also be used for transmitting a particular signal. Here the reference signal is fed to the waveform generator at each element. The waveform produced by the generator is fed to the high power amplifier, and then on to the free space. Phase shifting and time delay properties are used to steer the beam in a standard non-DBF. In DBF, the same process of beam steering is done by WFGs

The under mentioned techniques to process a signal are used by a DBF for enhancing radar performance:

(i) In receive mode beams to be digitally oriented for improved search occupancy.

(ii) Adaptively cancelling jammer presence.

(iii) Increase in resolution for both targets and jammers.

The analog time delay set ups have a greater error probability and therefore the wide band DBF can be used. The processing unit in DBF calculates and adds the in phase and quadrature component of signal to generate beam. If the auxiliary amplitude and phase weighing for the k-th element, $x_k$ is given by

$$w_k = \alpha_k e^{j\Phi k} \quad (7)$$

Then the output, y is given by

$$y = \sum_{k=1}^{M} w_k^* x_{k=w^H x} \quad (8)$$

Where,

$$w = \begin{bmatrix} w_1 \\ w_2 \\ . \\ . \\ w_m \end{bmatrix}, \text{ and } x = \begin{bmatrix} x_1 \\ x_2 \\ . \\ . \\ x_m \end{bmatrix}$$

### 1.3.2 Benefits of DBF

The main objective for implementing digital beam forming in electronically scanned radar is to provide multiple mediums in space domain for advanced signal processing algorithms to exploit. The following is achieved by DBF:

(a) Adaptive cancelling of jammers.

(b) Receiving multiple beams at one time.

(c) Angle estimation with large resolution.

(d) Increased dynamic range.

(e) Reduced phase noise on transmit.

(f) Digital time delay on transmit or receive.

(g) Array healing.

**DBF Implementation Challenges**

The key challenges of implementing DBF architecture are the following:-

(a) Packaging- Can the receiver be designed to fit within the available physical area?

(b) Power – Can the receiver and computing power consumption be kept within system constraints?

(c) Cost- Can the receivers and the beam forming computer be built at an affordable price?

(d) Interference- Can the receivers be made robust and sufficiently linear to handle strong interference?

(e) Alignment and calibration- Can the distributed receivers maintain adequate alignment and calibration?

(f) Reliability - Can the receiver be made reliable enough to achieve adequate system availability?

(g) Data movement – Can the digital data be communicated from the receivers to the beamforming computer in real time?

# CHAPTER 2

## 2. Objective

**2.1** The present research deals in understanding the relevance of Angle of arrival in the complex radar system. A network is designed to produce orthogonal beams that can be steered in different directions. The concept of Direction of Arrival is investigated and understood by comparing various algorithms. The following aspects are addressed in this report:

(i) Angle of Arrival in Beam Forming.

(ii) Design an Antenna Array for Beam Steering.

(iii) Beam Steering using Antenna Array in Jamming.

(iv) Comparision of DoA Techniques.

# 2. Literature Review

## 2.1 Antenna Array Design

### 2.1.1 Introduction

Phased arrays scanned with the help of an electronic beam are being used in many civil and military applications. However the exertion of the phased array is bound to base stations. The dominant impediment of deployment of the phased array in large scale is the high cost of the TR modules. The phase variation in the TR module is executed with the help of phase shifters which help in steering the beam in desired direction. A number of techniques are in practice for fabrication of the phase shifters but the cost remains at a higher reach by any of these fabrication techniques. The present area of research for beam steering electronically is ESPAR. Also beam steering is achieved using parasitic coupling and reactive bonding. The electronic phase shifting requires less number of phase shifters for the same amount of beam steering, thereby considerably reducing the cost. ESPAR antennas are fabricated using a dipole element constructed without a ground plane or using a monopulse element with ground plane. The monopulse design however is simpler in design and configuration.

### 2.1.2 Directive Beam-Steering Patch Array Antenna using Phase Shifter

In this paper the author has designed a main lobe direction varying patch antenna array using phase shifting technique. The design is primarily realised using a microstrip. The primary freq considered here is 10GHz for design and the single patch has the design as shown below:-

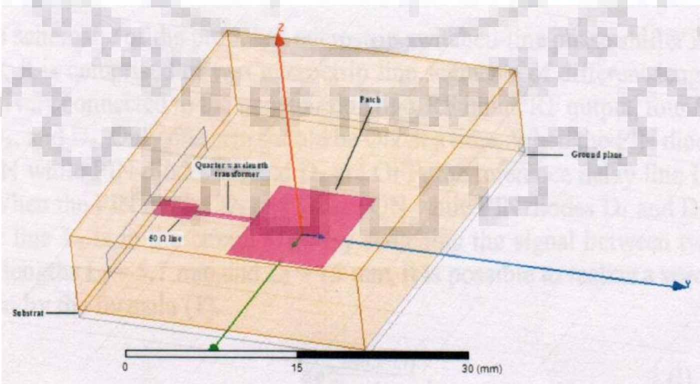



**Fig. 2.1. Geometry of SPA**

SOURCE: Conference paper by Abdelmajid Badri, May 2015 [8]

The calculation is undertaken using various reference formulae for the SPA and the set of readings is given by the table below:

**Table 2.1 Dimensions of SPA**

| Parameter | Value(mm) |
|---|---|
| Type of Substrate | RogerRT-Durroid |
| Length dimension of Substrate | 27.93 |
| Width dimensions of Substrate | 35.58 |
| Thickness dimension of Substrate | 0.79 |
| Width dimension of Patch | 11.86 |
| Length dimension of Patch | 9.31 |
| Feed-line Width dimension of Feed-line | 2.408 |
| Quarter wavelength transformer width | 0.5 |

All the elements have in the array patch need to have similar dimensions with exact inter element spacing in order to have accurate steering. The feed network is a T junction power divider with switch line phase shifters.

The concept behind the beam steering is equal power is fed to all the patches at the input of the phase shifters. As the Phase shifters have varying lengths in two arms, there is a change in phase and there by leading to steering. The specific phase shift is calculated using the formula

$$\Delta\varphi = \frac{2\pi(L2 - L1)}{\lambda} \quad (9)$$

$$\Delta L = L2 - L1 = \frac{\beta c}{2\pi f\sqrt{\xi_{eff}}} \quad (10)$$

The value of the output frequency is selected as per the application. The various results obtained of the parameters at different frequencies is tabulated below:-

## Table 2.2 PIN Diode Switches Configuration

**Table 1.** PIN diode switches configuration

| Type of phase shifter | Number of phase shifter | Phase shifter status | | |
|---|---|---|---|---|
| | | Case 1 | Case 2 | Case 3 |
| Microstrip switched line phase shifter | $S_1$ | $D_1$ and $D_3$ ON ($L_1$) | $D_1$ and $D_3$ ON ($L_1$) | $D_1$ and $D_3$ ON ($L_1$) |
| | $S_2$ | $D_1$ and $D_3$ ON ($L_1$) | $D_2$ and $D_4$ ON ($L_2$) | $D_1$ and $D_3$ ON ($L_1$) |
| | $S_3$ | $D_1$ and $D_3$ ON ($L_1$) | $D_1$ and $D_3$ ON ($L_1$) | $D_2$ and $D_4$ ON ($L_2$) |
| | $S_4$ | $D_1$ and $D_3$ ON ($L_1$) | $D_2$ and $D_4$ ON ($L_2$) | $D_2$ and $D_4$ ON ($L_2$) |
| Operating Frequency (GHz) | | 10.00 | 9.84 | 9.90 |
| Lobe Direction (deg.) | | 0° | 13° | 25° |
| Directivity (dBi) | | *11.41* | *11.51* | *11.32* |
| HPBW (deg.) | | 25° | 23° | 23° |
| Radiation efficiency (%) | | 90 | 93 | 89 |

SOURCE: Conference paper by Abdelmajid Badri, May 2015 [8]

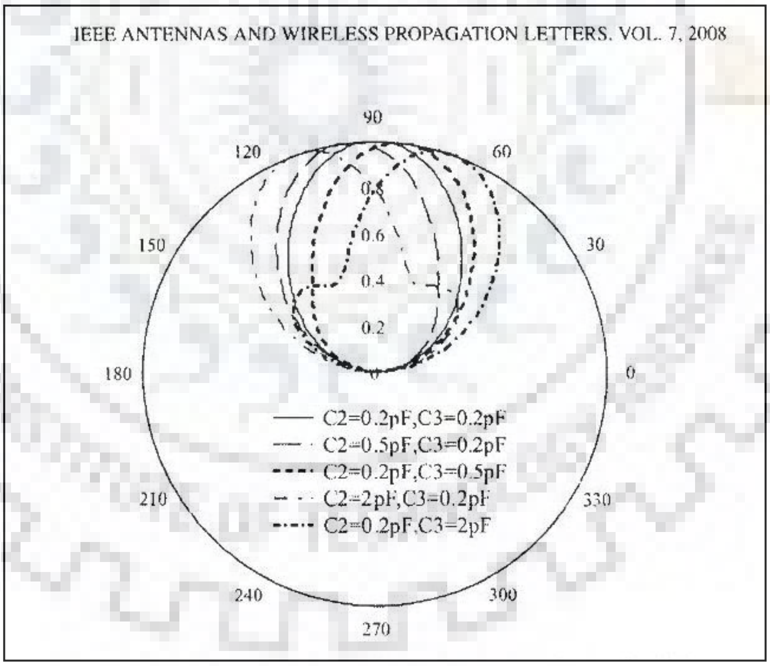



**Fig. 2.2. Radiation Pattern of ESPAR**

SOURCE: Paper on A low-cost Patch Antenna Phased Array by Yazid Yusuf and Xun Gong of 2008 [6]

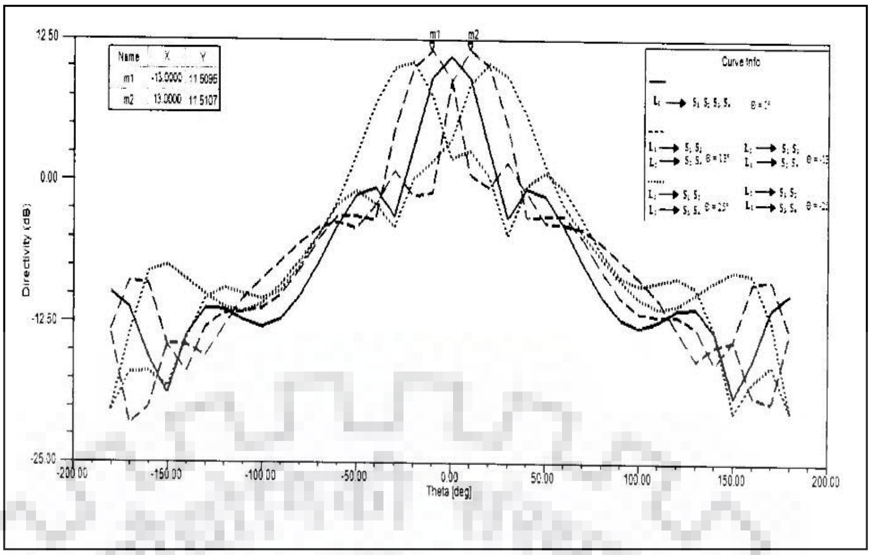



**Fig. 2.3. Comparison of Radiation Pattern by Phase Shifters**

SOURCE: Conference paper by Abdelmajid Badri, May 2015 [8]

### 2.1.3 Electrically Steerable Passive Radiator (ESPAR) Antennas

The author in the present study has designed an ESPAR by using a concept of varactor. The design is circular in shape with combinations of Active and passive elements embedded on to a ground plane which is encircled by a periphery. The active element is placed at the centre and the passive elements are on the outer boundary of the plane. The passive elements are connected through a hole to the varactor.

The radiation pattern is obtained from the set up when ac current is passed on to the passive elements, with and without periphery. It is observed that the radiation pattern is much simpler when used on the monopulse design.

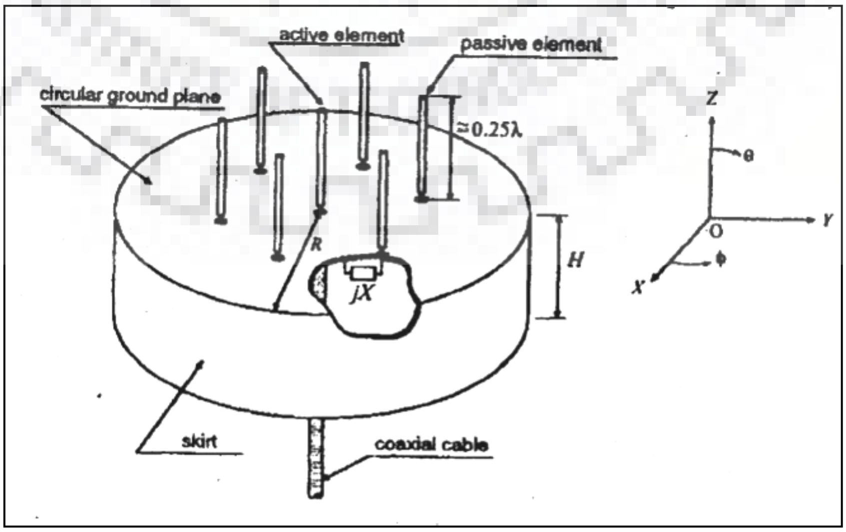



**Fig. 2.4. Configuration of 7 Element ESPAR**

SOURCE: Paper on Electrically Steerable Passive Array Radiator antennas of 2005 [7]

The configuration used by the author is shown above. Here the active element is surrounded by the passive elements. The spacing is 0.25 λ and the length of each element is also 0.25 λ.

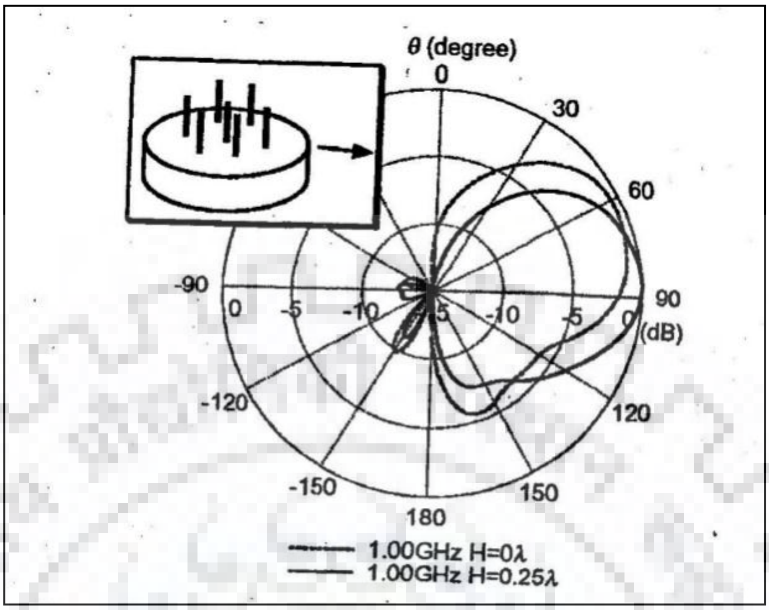



**Fig. 2.5. Elevation Pattern of 7 Element ESPAR Antenna**

SOURCE: Paper on Electrically Steerable Passive Array Radiator antennas of 2005 [7]

The radiation characteristics of the monopulse antenna are shown above. The power gain is the function of radius in azimuth. The gain reduces without periphery with increase in radius. With periphery the gain reduces till 0.5λ and subsequently reduces. ESPAR antennas give out high gain beam in the horizontal plane for any means of communication. The elevation pattern of the 7 set of elements is shown below and it is seen that the radiation pattern is the function of elevation angle. The varactor diode is connected to the passive elements and is supplied by voltage to act as reflectors and the other passive elements act as directors.

### 2.1.4 Beam Controllable Microstrip Antenna with Switching Diodes

In this study the author analyses the beam controllable microstrip patch. A horizontal plate is taken as a set up in which four slots acting as parasitic patches are made at the outer surface and one slot is at the centre is the fed patch. The slot design has a polarisation control function. The polarisation of the antenna set up can be changed by changing the bias voltage.

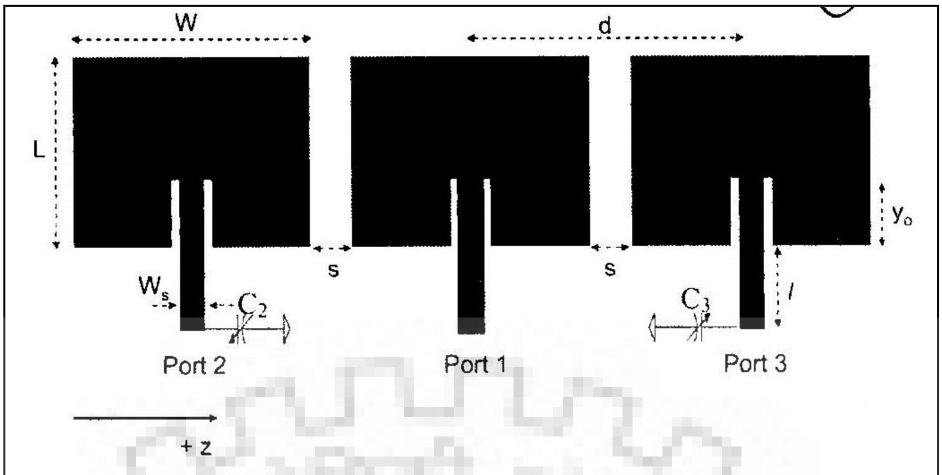



Fig. 1. Geometry of a three-element ESPAR patch antenna phased array. ($W = 35.0$ mm, $L = 28.3$ mm, $W_S = 3.8$ mm, $S = 6.0$ mm, $d = 41.0$ mm, $l = 6.0$ mm, $y_0 = 10.0$ mm).

**Fig. 2.6. Geometry of 3 Element ESPAR Patch Antenna**

SOURCE: Paper on A low-cost Patch Antenna Phased Array by Yazid Yusuf and Xun Gong of 2008 [6]

In this design, the centre slot is the feed point and the other slots are parasitic. The parasitic slot has a pair of diodes connected over the plane of the strip. The diodes control the surface current diffusion. The centre patch is energised by probe and the four parasitic patches are excited by collective coupling. The directivity is varied by bias voltage of the diodes.

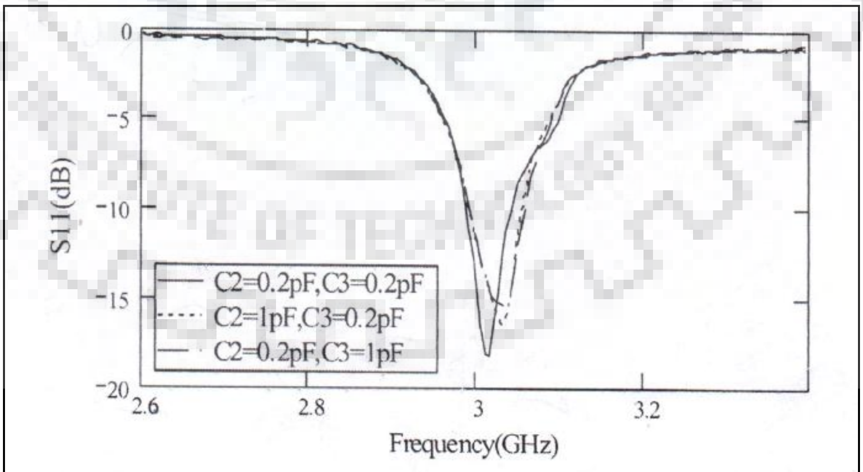



Fig. 7. Measured return losses of the ESPAR phased array for different reactive loadings corresponding to beam scanning angles of −20, 0, and 20 degrees (relative to the boresight), respectively.

**Fig. 2.7. Return Losses in ESPAR Antenna**

SOURCE: Paper on A low-cost Patch Antenna Phased Array by Yazid Yusuf and Xun Gong of 2008 [6]

In the parasitic patch, the diode polarity governs the frequency of operation. The frequency of operation is greater when the diodes are ON and the frequency is lesser when the diodes are OFF and in-turn controlling the current in the parasitic patches. And as the resonant frequency of the fed patch is set, the mutual coupling of the patches is as per the ON/OFF state of parasitic patches.

## 2.2 AoA Techniques

### 2.2.1 Introduction

An antenna array is the collection of antenna elements which are used in different combination to realise the beam forming from the array. The main goal of the array design and the array processing is to reduce the SNR of the incoming signal and thereby increasing the detection of correct signal. This leads to estimation of accurate data about number of sources/targets such as detection of speed, range and direction. There are many types of DoA algorithms that are in use from in the field. The estimation of the algorithms depends on the application. The conventional beamforming algorithms are simple and require low computation but have low resolution. The subspace based algorithms that carry out Eigen decomposition of the system into signal and noise sub spaces for processing.

### 2.2.2 Comparative Analysis on Direction of Arrival Estimation Techniques

In this study the author compares the various DoA algorithms with the assistance of a signal model by varying the signal parameters such as SNR, no of snap shots and size of the array. The author uses a signal model with M sources and N array elements to determine the angle dependency in covariance matrix form of the different algorithms.

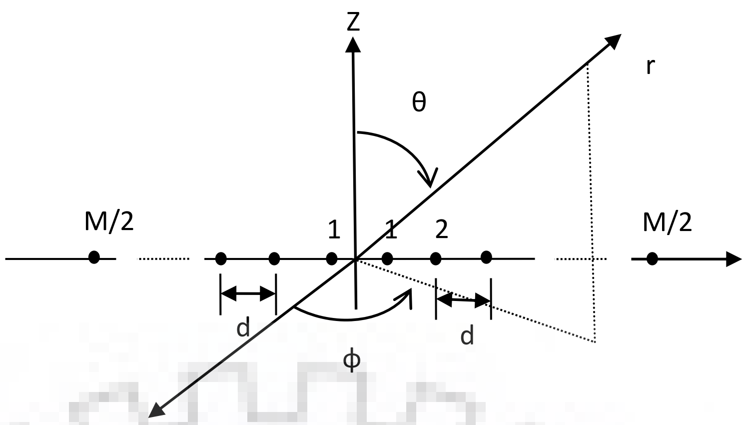



**Fig. 2.8. Linear Array Set-up Signal Model**

The author examines that in case of the sub space based techniques, where the signal is separated into signal and noise components, the larger Eigen values represent the signal part and the lower Eigen values represent the noise component. It is interpreted that in the classical beamforming, the algorithms runs for maximum power in the spectrum and exempt the localisation of a point because of the power contribution from the adjacent directions.

### 2.2.3 Comparative Study between Several Directions of Arrival Estimation Methods

In this study the author correlates various DoA estimation techniques in the beamforming process and is restricted to one dimensional stationary case i.e. stationary source. The signal sources are entrusted by AWGN noise in order to compare the realisation of various algorithms. It is highlighted in the study, that the sub space based techniques for DoA estimation are limited by large number of array elements and can be worked upon by the propagator method. However the propagator method is only useful when the noise present in the system is Gaussian in nature.

In the test set up as shown above, the scanning of the array elements is done from (- π/2, π/2). The output signal y(t) is evaluated using a weight vector w with the receiving data x

$$y(t) = w^H x(t) \qquad (11)$$

The principle behind the linear prediction method is that it maximises the mean output signal power of array elements subject to restricting the weights on the slated elements to unity. The capability to resolve depends on order of the element in the array, which in turn depends on the SNR & minimum angle separation. The Maximum Entropy algorithm is the advanced version of beam forming approach. It is based on the extrapolation of the co variance matrix. The coefficient of auto regressive (AR) model is selected in such a manner that it minimises the expected predictor error.

The propagator method does not utilise the Eigen decomposition for calculation as used by the other sub space methods. It uses the signal and noise both as composite single system to fetch the propagation operator. It is suitable for the White Gaussian noise and its performance degrades in spatial non-uniform coloured noise.

The covariance matrix is given by the expression

$$\widehat{R}_{xx} = [R_1 \quad R_2]^T$$

In the noiseless system, it is represented as

$$w = \frac{\widehat{R}_{xx}^{-1} u}{u^H \widehat{R}_{xx}^{-1} u} \qquad (12)$$

### 2.2.4 Minimum Variance Distortion less Response Beamformer With Enhanced Nulling Level Control

In this study the author primarily focuses on the adaptive beam forming and studies the MVRD technique for DoA estimation. The MVDR algorithm is adequate of resolving signal targets even if they are minor multiples of the beam width. In this approach, the algorithm maximises the sensitivity of the signal in one direction and alters the weights accordingly. By this technique we calculate the minimum separation between two adjacent users in space, thereby giving the wider spectrum for use and also increase in channel capacity.

The interference is suppressed by increasing the SNR value of the signal and lowering the noise content. The algorithm also confides on the incident angle of the incoming signal which in turn depends on the weight values. In the direction of the signal, the output power must be subject to unity gain. The optimum weights correspond to the steering value of the signal when maintaining unity gain. The MVDR adaptive algorithm is given by

$$W_{MVDR} = \frac{R^{-1} a(\theta)}{a^H a(\theta) R^{-1} a(\theta)} \qquad (13)$$

The value of the beamformer weights is finalised depending on the number of users and also at the same time in the direction of the originator a unity gain. The output signal is maximised by increasing the output SNR. The MVDR Beamformer is unsuitable for more than one path as it maximises the power in one direction at one time. Also the number of interfering sources is governed by the degree of freedom of the sources.

The Null level is enhanced by the use of Dynamic mutation, which is represented by

$$w = \frac{\widehat{R}_{xx}^{-1} u}{u^H \widehat{R}_{xx}^{-1} u} \tag{14}$$

By the use of AIS iteration processes, the MVDR algorithms develops a deep null in the direction of the interfering signal, thereby leading to achieve max SNR. In two dimensional layout , the weight values in the set of iterations is given by

$$W_{NM} = \begin{bmatrix} w_{mvdr1} & w_{mvdr2} & w_{mvdr3} & w_{mvdr4} \\ w_{11} & w_{12} & w_{13} & w_{14} \\ . & . & . & . \\ . & . & . & . \\ w_{n1} & w_{n2} & w_{n3} & w_{n4} \end{bmatrix}$$

### 2.2.5 Comparison of Direction of Arrival (DoA) Estimation Techniques for Closely Spaced Targets

In this paper, the author discusses the importance of DoA with a goal to form an antenna array. The result achieved by forming an antenna array is, increase in SNR, details about no of targets and the direction. Spatiotemporal filtering is required for moving signal to obtain the above parameters.

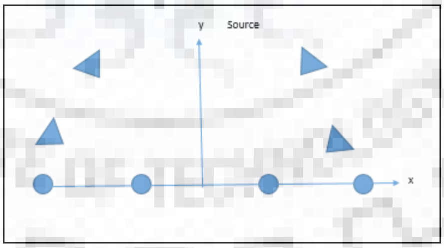



Fig 2.9. Multiple signals incident on ULA.

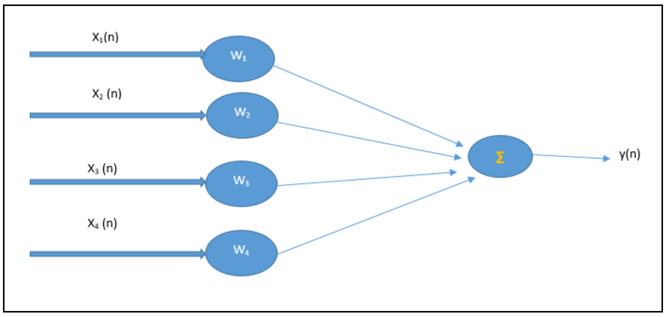



**Fig. 2.10. Beam former**

The author in this paper considers a one dimensional identical set of elements (ULA) for processing of the beam. The noise approaching the antenna is considered to be white Gaussian. The ESPRIT algorithm is based on translational invariance structures of the array sensors. The algorithm does not require an in-depth search on all possible viewing vectors for calculation of DoA.

**Table 2.3. Summary of Beam Forming Algorithms**

| Algorithm | Resolution | Complexity | General Remarks |
|---|---|---|---|
| CBF | Poor | Easily implementable steps, Search in one plane only. | Main lobe dimensions decide the Resolution |
| MVDR | Good | Inverse of R, Search in one plane only. | More susceptible to presence of noise. |
| MUSIC | Very Good | Eigen categorisation, Search in one plane only. | Source calculation. |
| ESPRIT | Excellent | Eigen categorisation, Calculating Ψ | Operates in pairs. |

### 2.2.6 Performance Analysis of MUSIC and MVDR DoA Estimation Algorithm

In this paper the author discusses the emphasis on requirement of high system capacity. The received signal at receiver is same as the transmitted with addition of noise and interference components. Here it is discussed the use of Antenna with high bit rate and higher quality in the band spectrum. The comparison of MVRD and MUSIC algorithms is done and various parameter are discussed with the help of array design. Here it is seen that both these algorithms are primarily dependent on array size aperture. The resolution is poorer in case of MVDR in comparison to MUSIC.

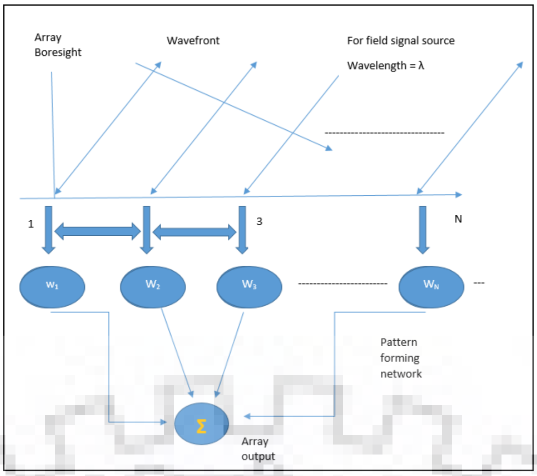



**Fig. 2.11. Uniform Linear Array with M-Elements**

The author carries out the simulation of both the algorithms using MATLAB. The performance results are studied and it is observed that the peaks in the MVDR spectrum are obtained when the steering vector is perpendicular to the noise sub space. This leads to minimum contribution of the undesired signals, by maximising the output power with unity gain in the look up direction.

# 3. Antenna Array Design

A single element in an array has less directive gain and has a broader radiation pattern. The high gain antennas are a primary requirement of long distance applications. The high gain parameter can either be achieved by increasing the size of the antenna assembly or otherwise by having a assembly of radiating elements referred to as an array.

The net field emitted by two elements with no mutual coupling is denoted by:-

$$E_t = E_1 + E_2 = \hat{a}_\theta j\eta \frac{kI_0 l}{4\pi}\left\{\frac{e^{-j[kr_1-(\beta/2)]}}{r_1}\cos\theta_1 + \frac{e^{-j[kr_2+(\beta/2)]}}{r_2}\cos\theta_2\right\} \quad (15)$$

$\beta$ denotes inequality in phase excitation in the elements. The total field of the data structure is the multiplication of one element field and the antenna weight positions. The array factor for the assembly having two elements is represented by:-

$$AF = 2\cos\left[\frac{1}{2}\left(kd \cos\theta + \beta\right)\right] \quad (16)$$

The normalised form is asserted by the expression:-

$$\left(AF\right)_n = \cos\left[\frac{1}{2}\left(kd \cos\theta + \beta\right)\right] \quad (17)$$

The excitation phase of the antenna array is the measure of the order of the array. The field aggregate of the data structure can be contained either by differing the phase or separation amid the elements. The distant field measurement of the two identical elements is the multiplication of one field and the order of the array.

That is E (total)=[E(single element at reference point]x[array factor]

This is attributed as superimposition of pattern of array having identical elements. The array factor depends on no of elements present in the array, their computational geometry, relative phase and arrangement and the spacing. As the arrangement of antenna weights is independent of the directional properties, the elements can be interchanged by isotropic sources.

The array factor for N element array can be attained by taking into account the elements to be point sources and is given by

$$AF = \sum_{n=1}^{N} e^{j(n-1)(kd\cos\theta+\beta)} \tag{18}$$

This can be written as

$$AF = \sum_{n=1}^{N} e^{j(n-1)\psi} \tag{19}$$

Where $\psi = kd\cos\theta + \beta$

In order to have absolute radiation of an array aimed perpendicular to the layout line of elements set up, there needs to be a proper selection of type of radiators and the order of the array. The first peak of the order of the array arises by the mode

$$\psi = kd \cos\theta + \beta = 0$$

The first maxima is planned for at $\theta_0 = 90^\circ$, then

$$\psi = kd \cos\theta + \beta|_{\theta=90^\circ} = \beta = 0$$

In order to have a highest order of the array towards the broadside of the array, it is imperative that gross elements to have identical phase excitation. Once the separation between the elements is of the multiples of wavelength, it leads to grating lobes ($d = n\lambda$ ,n=1,2,3....) when $\beta = 0$. If $d = n\lambda$, n=1,2,3.....and $\beta = 0$, then

$$\psi = kd \cos\theta + \beta|_{\substack{d=n\lambda \\ \beta=0 \\ n=1,2,3.......}} = 2\pi n\cos\theta|_{\theta=0^o} = \pm 2n\pi$$

It is required to main beam maxima in the data structure arrangement, the maximum spacing should be one wavelength. For d=L/2, max radiation is in the both directions (@=0 and @=180). For element spacing of factor of the wavelength (d=ny, n=1,2,3.....), along with having maximum radiation along axis, their also exists maxima at orthogonal to the axis of array.

Thus, by regulating the cumulative phase gap on the element data structure, the direction of superlative field of line can be varied to form a array scan. In case of phased array, the scanning must be continuous in order to have a continuous progressive phase change.

### 3.1 Planar Array

The particular shape array is realised by placing the radiator along the shape of the array. Planar arrays give practical results and do not have a fixed line of pointing of the beam for carrying out beam scanning of the main beam. A directive beam steering antenna array has been designed by adopting switched line phase shifters. There array consists of a combination of metallic dielectric antennas, energy splitters and frequency shifters printed on a Roger RO 4232 with h=1.52 mm and a di-electric constant of 3.2 with dimension of 28.3 X 30 $mm^2$.

The relative shift with time in an electromagnetic wave of a particular frequency can be altered when propagating over a transmission line adopting a phase shifter. A reconfigurable antenna has three measurable fields i.e. adaptive frequency, polarisation and radiation pattern. The reconstructing antenna can be realised using RF switches such a PIN Diodes, MEMs and GaAs FET. By wavering the switch into ON and OFF, is determined if the feed line receives the RF signal.

In the paper referred the study on the extent of beam steering of primary beam by using atomic switch phase varying devices is given. The phase varying switching devices are only contingent on length of the used. A decisive edge of this circuit is that the phase varying will vary as per the frequency. This enables the circuit to have more range of frequency for operation.

### 3.2 Design and Analysis of Beam Steering Antenna Array Adopting Phase Shifter

#### 3.2.1 Single Patch Antenna

The microstrip patch antenna is equivalent to a single element antenna with an advantage in applications requiring the usual size array. The primary radiating microstrip antenna are achieved at a frequency of 3 GHz, which gives a single patch antenna as shown below

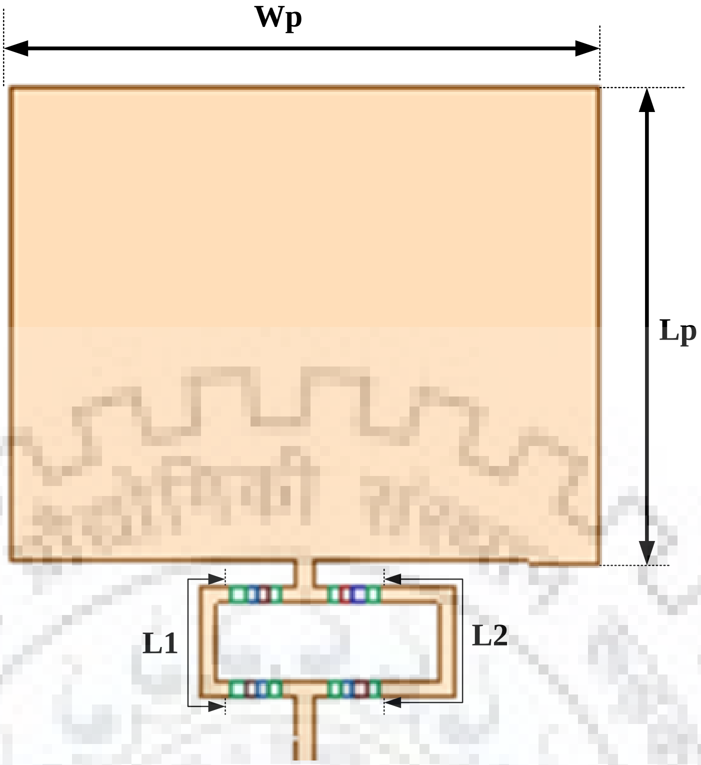



**Fig.3.1. Geometry of Single Patch Antenna**

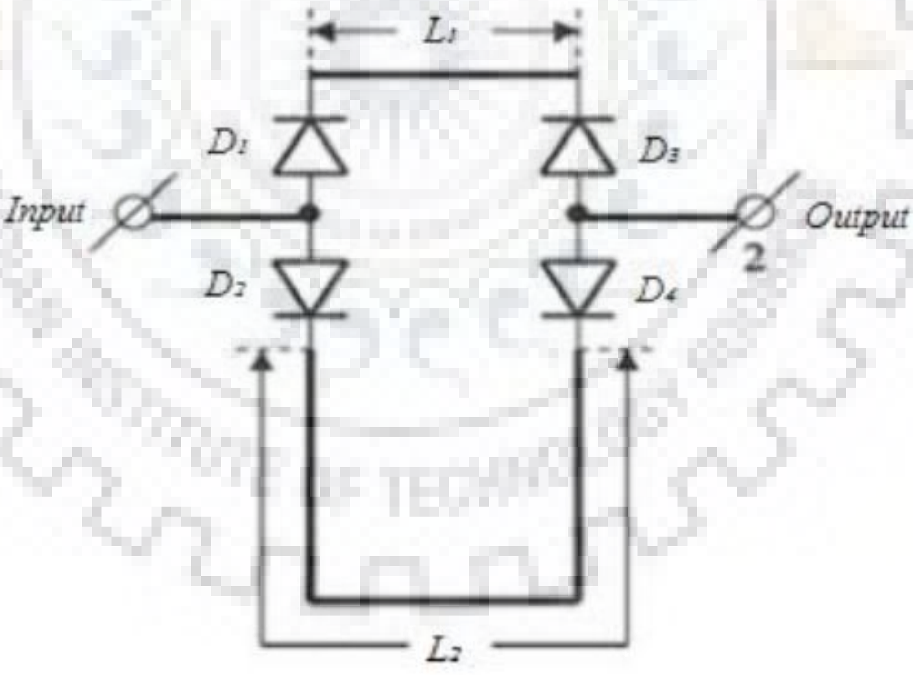



**Fig. 3.2. Phase Shifter**

SOURCE: Conference paper by Abdelmajid Badri, May 2015 [8]

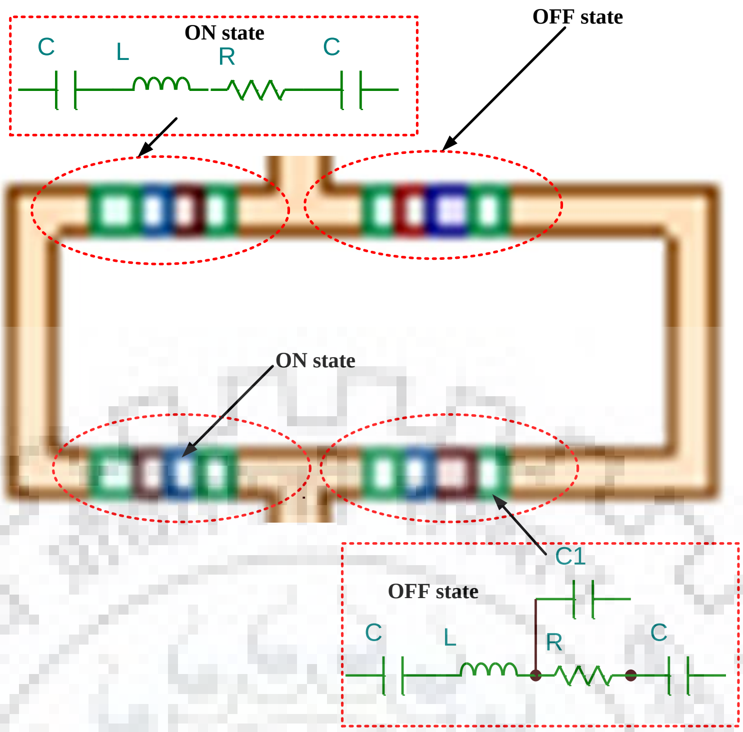



Fig. 3.3 Equivalent Circuit of Phase Shifter

### 3.2.1.1 Beam Steering of Antenna Array using the Phase Shifter.

A constitution of four SPA is contrived to induce a antenna which can swivel the beam in a specified direction. All the elements have akin extent and virtue. The dimensions of SPA are 28.3 X 30 $mm^2$. There must be an accurate determination of the defile between the coterminous elements so as to get aggrandised antenna performance. The IES is realised to be greater than half wavelength in maximum array cases. The circuitry furnishing the input is constituted of three Wilkinson's power divider and four microstrip switched lines phase shifters printed on the same Roger RO 4232 with h=1.52 mm and a di-electric constant of 3.2 As the patch antenna are furnished with identical phase, the array output is of quadratic nature with respect to array. To actualize the energy distribution of main lobe, the micro-strip switched line phase shifters are used to recompose the delay path.

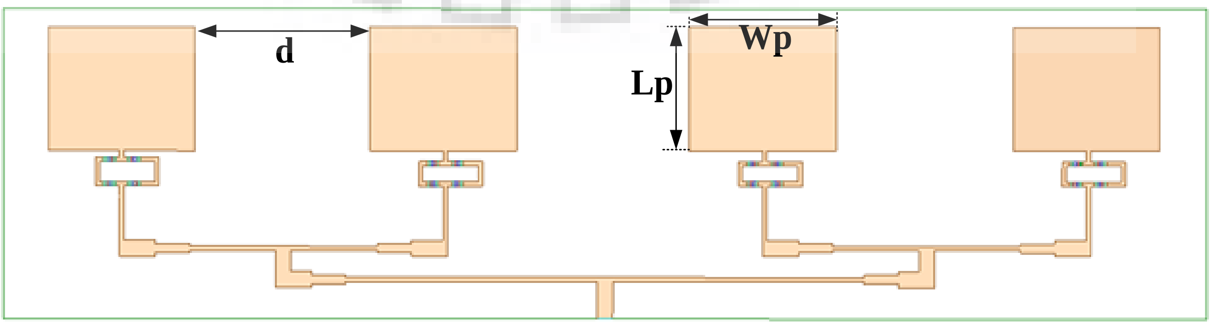



Fig. 3.4. Geometry of Antenna Array

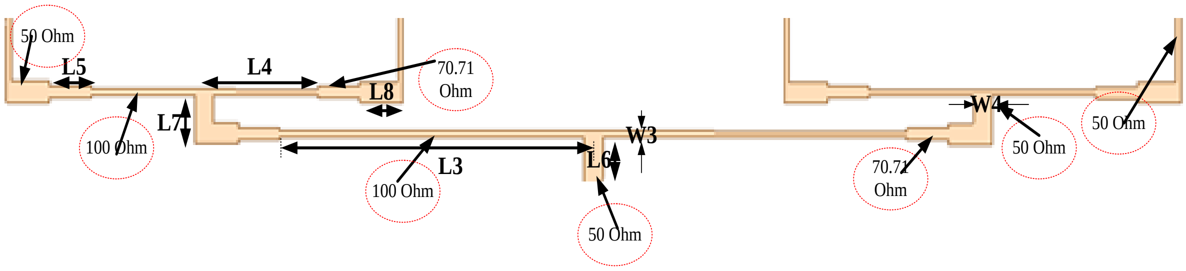



**Fig. 3.5 Detail of Micro strip Feed line Network**

The elemental schematic of schemed microstrip switched-line phase shifter is shown above. The same is proposed of two micro strip line wedges of varying lengths (L1 and L2) carefully amalgamated to the transmission line, RF input, RF output, equivalent circuit diagram consisting of R, L and C of diodes D1,D2,D3 and D4. At any instance, only one path should be progressive. When the upper set of diodes forward biased, then lower set of diodes are not operating, and the relating L1 is part of circuit. When the other circuit is in operational polarity, then L2 forms part of the set up. By interchanging the operational parameter among circuits of varying perimeter, the specific transmute in phase can be resolved by the formula

$$\Delta\varphi = \frac{2\pi\left(L_{d2} - L_{d1}\right)}{\lambda} \tag{20}$$

However, as this trace is realised using micro strip transactions, the gross length L is calculated by the formula

$$\Delta L = L_{d2} - L_{d1} = \frac{\beta c}{2\pi\sqrt{\varepsilon_{reff}}} \tag{21}$$

Where c is the light characteristic depicting speed and β is the factor governing wave front.

The imitation results depict that the designed element layout has profitably accomplished the look capability of the entire area including beam steering as also improvement in the direction accuracy and least losses due to structure matching properties are maintained in the entire range of angles. The calculations make the antenna arrangement advisable for military applications.

## 3.3 Results and Discussion

The simulated S11 of the antenna array in two different modes, When D1 and D3 ON as shown in Fig.11 and other is D2, and D4 is ON as shown in Fig. 12. The difference in the results may be attributed to the delay line of the structure. The calculations made using tools for reflection coefficient (S 11) are less than -10 dB for both cases are shown in Fig. 13.

The algorithm output results of peak realized gain (both cases) of this design as shown in Fig.14. These two curves are good agreement with each other at the resonant frequency (D1 and D3 is ON: 8 dBi, D2, and D4 is ON: 8 dBi).

The simulated efficiency was 80-90 % (both cases). The theoretical results of radiation efficiencies are shown in Fig.15.

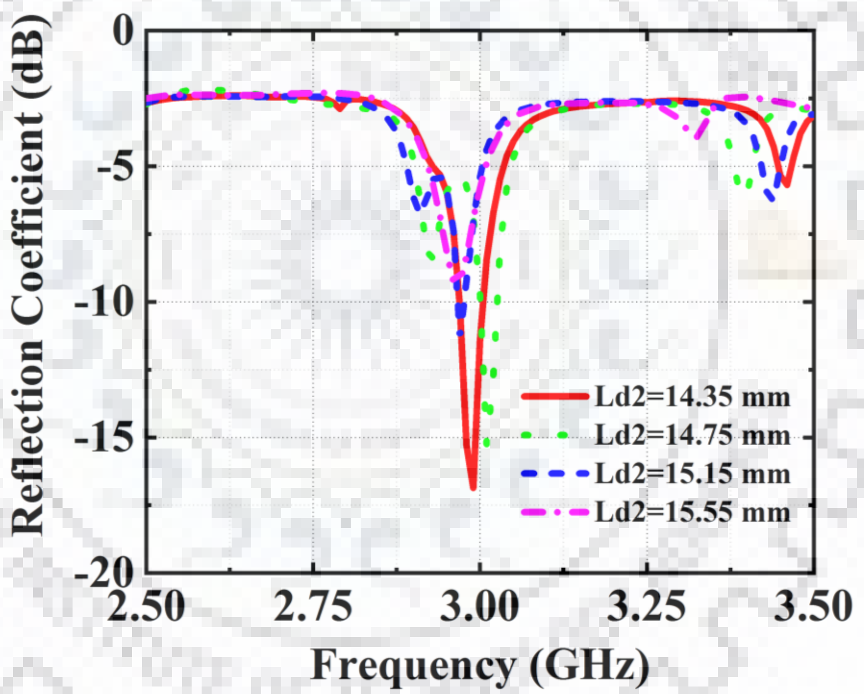



**Fig.3.6. Effect of Ld2 (D1 and D3 ON) on Reflection Coefficient**

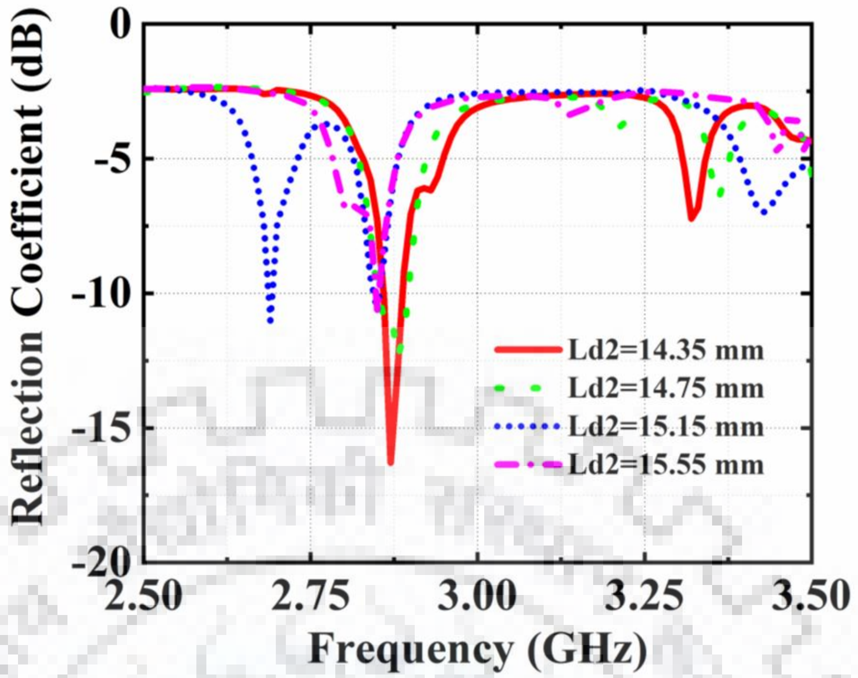



**Fig. 3.7. Effect of Ld2 (D2 and D4 ON) on Reflection Coefficient**

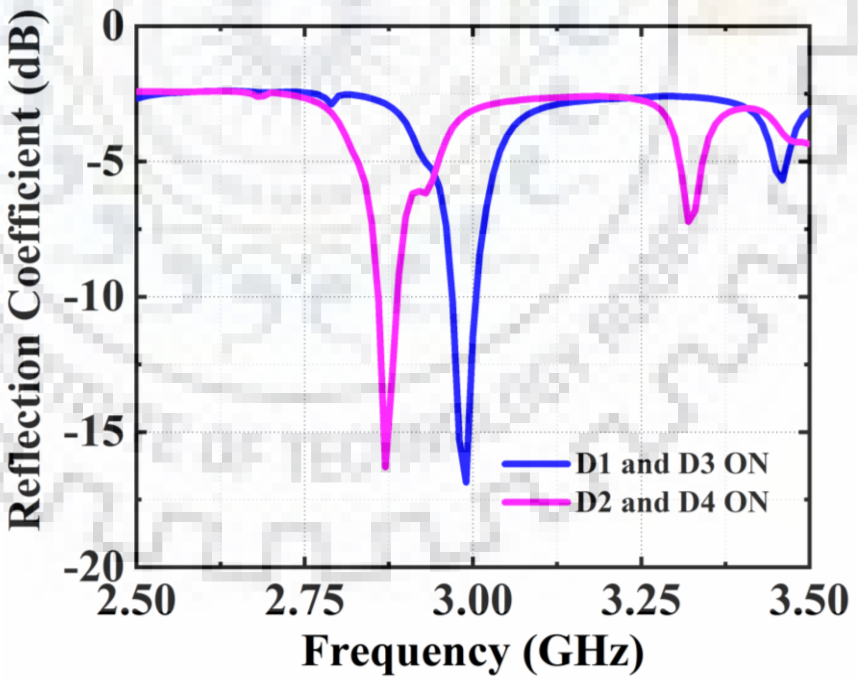



**Fig.3.8. The Simulated Reflection Coefficient**

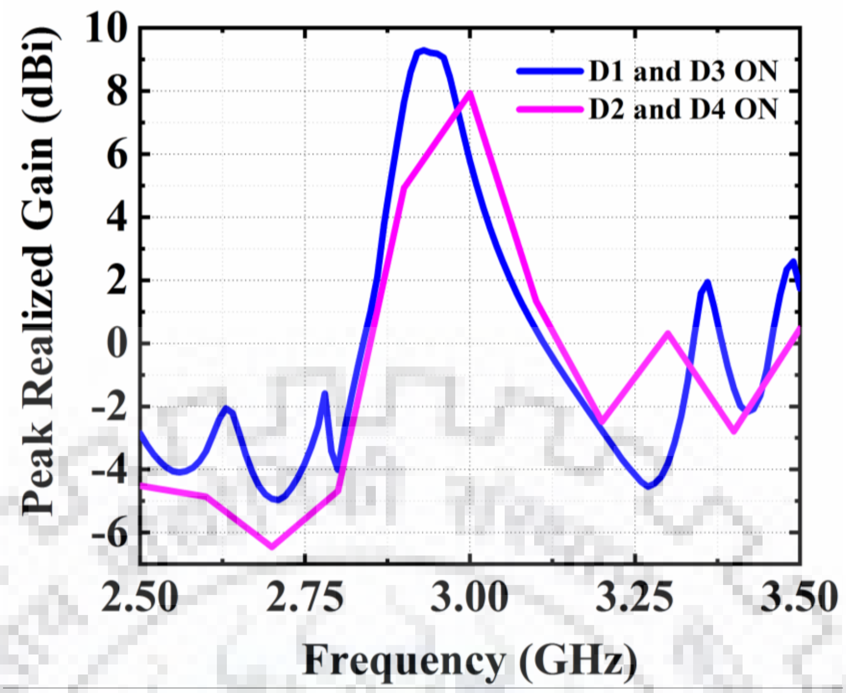



**Fig. 3.9. The Simulated Peak Realized Gain**

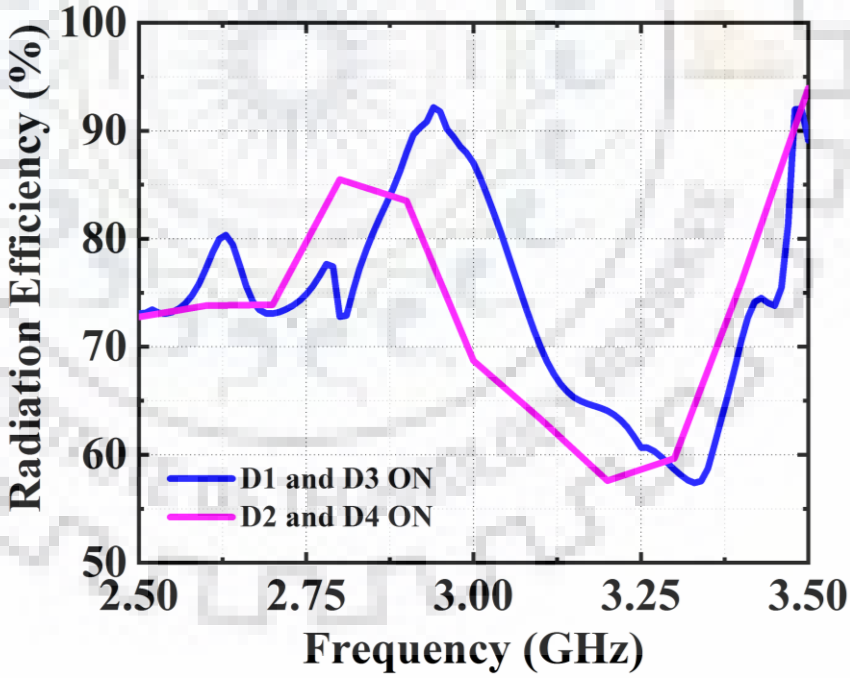



**Fig. 3.10. The Simulated Radiation Efficiency**

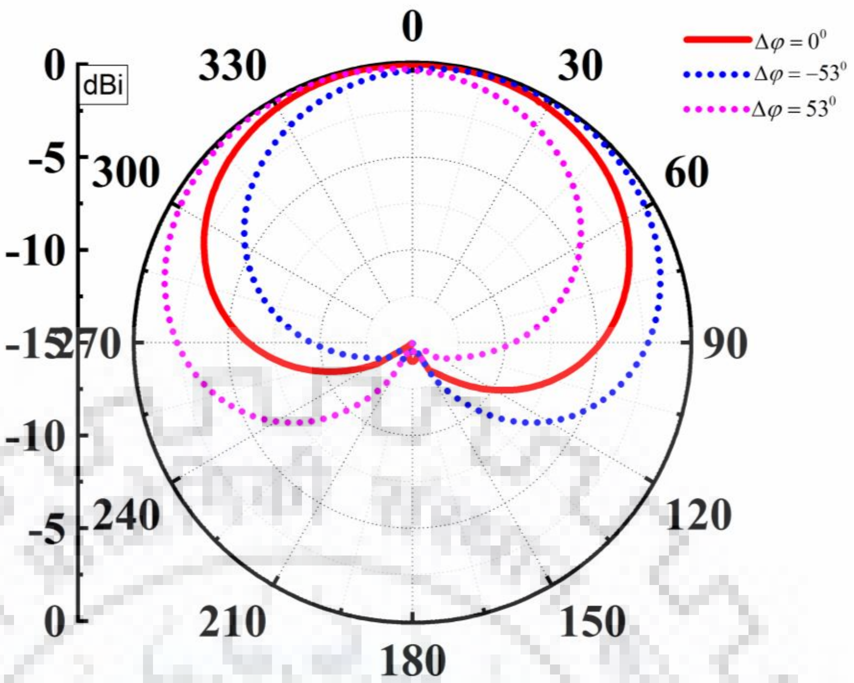



**Fig. 3.11. Comparison of Radiation Pattern by certain Phase Shifters Configuration in Polar Plot**

The simulated radiation pattern of E-plane is shown in Fig. 16. Due to optimization of the delay line of the microstrip transmission line and proper operating the four diodes in different positions are control the beam steering. By using a formula of and optimized by $L_1 = L_{d1}$, and $L_2 = L_{d2}$ to fixed $\Delta\varphi = 0^0, -53^0$, and $53^0$ at resonance frequency at 3 GHz.

# CHAPTER 4

## 4. DoA Estimation

Evaluation of the direction of the impending signal is referred to as Direction of Arrival (DoA) of the signal property. DoA estimation holds a major importance in applications such as Radar, Electronics Surveillance Navigation and detection of targets. There are different types of estimation techniques/algorithms designed to evaluate accurate incoming angle. The spectral based techniques rely on the formation of a spectrum with respect to the signal parameter and the parametric type of function evaluates and searches all parameters of the signal component.

The highest measure of the power is in the direction of the source emanating signal. Bartlett's technique and MVDR Technique are two major techniques to study the Angle of Arrival concept. These techniques are easy to calculate but are hampered by low resolution of targets. On the other hand the sub space based techniques, utilise the Eigen based decomposition to extricate the signal component. The principle of Sub space based techniques is to divide the signal component into noise and signal. Eigen vectors of various Eigen values are generated. The larger Eigen values correspond to the signal component and the menial scalar set values correspond to noise component. The array steering vector is always quadratic to the noise subspace.

Rotational Invariance Techniques (ESPRIT) and Minimum Norm [45] are a different form of the beam forming techniques. These algorithms are not suitable for real acoustics ambience and lead to minimal response.

### 4.1 Data Model

Consider a singular wavelength plane wave having monochromatic variations so that the delay between each element is given by

$$\tau = \frac{d \sin \theta_i}{v} \tag{21}$$

The signal on the particular nth element is depicted as:

$$x_k(t) = e^{-jw\tau_k} x_1(t) = e^{-j\frac{2\pi}{\lambda}d(k-1)\sin\theta} x_1(t) \tag{22}$$

Output of one array element at any given time t0

$$x_k(t) = \sum_{i=1}^{M} s_i(t)\, e^{-j\frac{2\pi}{\lambda}d(k-1)\sin\theta_i} + n_1(t) \quad (23)$$

Forming N element samples in a vector form leads to the expression:-

$$x(t) = [x_1\ x_2 \cdots x_N]^{\tau} = \left[1\, e^{-j\psi} \cdots\cdots e^{-j(N-1)\psi}\right]^T s(t)$$
$$a(\theta)s(t) \quad (24)$$

Where,

$$\xi_i = -\frac{2\pi f_c}{v} d \sin\theta_i$$

Conventional non adaptive beamforming carries out the measurement of the weighted sum of the signal and is given by

$$z = h^{/}\ y \quad (25)$$

The vectored value of the complex weights can be represented by

$$h = \left[w_0\ w_1 e^{+jK_\theta} \quad \ldots\ldots\ldots w_{N-1} e^{+j(N-1)K_\theta}\right]^{/} \quad (26)$$
$$h = w^{/} \odot a_s(\theta)$$

Now, let the weights be matched for an incoming signal angle and the array is assumed to be pointing towards .The beam forming response for the incoming signal at $\theta_0$ is given by

$$z(\theta) = h^{/} y = \hat{A} \sum_{n=0}^{N-1} \alpha_n e^{-j(K_\theta - K_{\theta 0})n} \quad (27)$$

The response of the beamformer in the above example can be related to a matched filter response for a particular value of output.

Suppose it is desired to maximise the output, then the response of a system is given by

$$h = k\ S_I\ t^* \quad (28)$$

Now, consider a complex signal column

$$y_m = [y[m]\ y[m-1] \ldots\ldots\ldots\ldots\ldots\ldots\ldots y[m-N+1]]$$

$$h = [h[0] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots h[N-1]]^{/}$$

Output is given by

$$z = h^{/}\ y \qquad (29)$$

Then the power in the output signal = $z * z^{/}$

$$= h^{H} y^{*} y^{/} h \qquad (30)$$

Therefore the signal power is represented as

$$h^{H}\ t^{*}\ t^{/}\ h \qquad (31)$$

And the Noise power is given by

$$h^{H}\ w^{*}\ w^{/}\ h \qquad (32)$$

As the noise power is Gaussian in nature, the noise power in represented in the form of covariance matrix as

$$S_{I} = E\left[ w^{*}\ w^{/} \right] \qquad (33)$$

The ratio of signal to noise power known as SIR is given by

$$SIR = \frac{h^{H}\ t^{*}\ t^{/}\ h}{h^{H} S^{I} h} \qquad (34)$$

Applying Schwartz inequality on the above equation as it holds correct in that relation, we get,

$$\left| p^{H} q \right|^{2} \leq \left| p \right|^{2} \left| q \right|^{2} \qquad (35)$$

Defining, the following variables in the Schwartz inequality, we get

$$p = Ah$$

$$q = \left( A^{H} \right)^{-1} t^{*}$$

$$p^{H} q = h^{H} t^{*}$$

$$\left| p^{H} q \right|^{2} = h^{H} t^{*} t^{/} h$$

$$h^{H}\ t^{*}\ t^{/}\ h \leq \left| Ah \right|^{2} \left| \left( A^{H} \right)^{-1} t^{*} \right|^{2}$$

$$= \left(h^H\ S_I\, h\right)\left(t^1\ S_I\ t^*\right)$$

$$SIR \le t^/\ S_I^{-1}\ t^*$$

$$h_{opt} = S_I^{-1} t^*$$

The optimum filter response for any incoming signal is given as

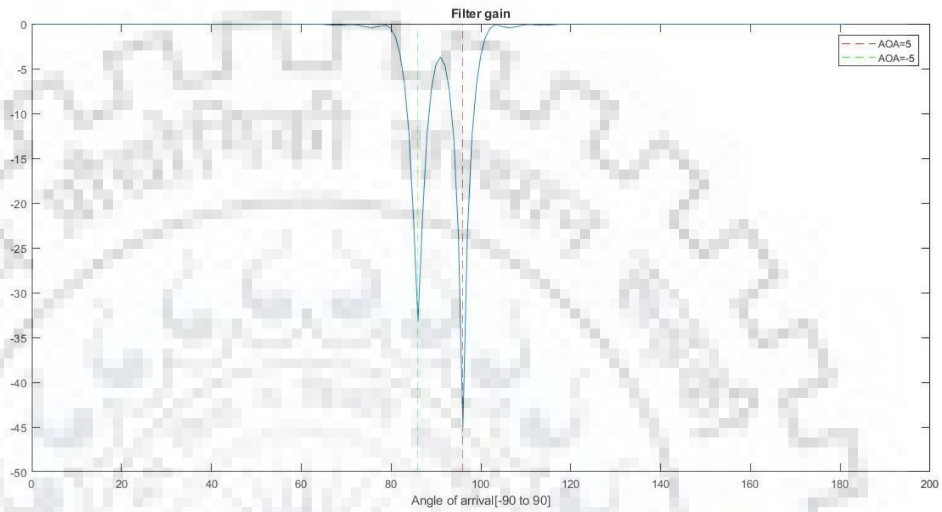



**Fig.4.1. Matched Filter Response**

Vector matched filter approach leads directly to an analogy that the array antenna weight vectors can be used to steer the zero's of any antenna pattern. This capability is very useful in combating the presence of jammers in the signal space.

The antenna pattern that maximises the o/p in any environment is given by

$$h = k\ S_I\ t^*$$

However, the covariance matrix of interference should be modified for the presence of the interfering jammers other than the noise in the environment. The Jammer signal is given by:-

$$J_n(t) = \sigma_J^2 w(t) e^{j\left[\Omega(t - nd\sin\theta/c) + \phi_0\right]}$$

$$= \sigma_J \hat{w}(t_0) e^{-jK_\theta n}$$

In vector form, the jammer signal is given by

$$J = \sigma_J \hat{w}(t_0) a_s(\theta)$$

The covariance matrix formed by the presence of the jammers in addition of the environment noise is given by:-

$$S_J = E\left\{J^* J'\right\} = \sigma_J^2 E\left\{\left|w(t_0)\right|^2\right\} a_s^*(\theta) a_s'(\theta)$$

$$= \sigma_J^2 \, a_s^*(\theta) a_s'(\theta)$$

$$= \sigma_J^2 \begin{bmatrix} 1 & e^{-jK_\theta} & \cdots & e^{-j(N-1)K_\theta} \\ e^{+jK_\theta} & 1 & e^{-jK_\theta} & e^{+j(N-1)K_\theta} \\ \vdots & \vdots & \ddots & \vdots \\ e^{+j(N-1)K_\theta} & e^{+j(N-2)K_\theta} & \cdots & 1 \end{bmatrix}$$

The added covariance matrix including the jammer components is given by

$$S_I = \sigma^2 I + \sum_{p=0}^{P-1} S_{J_P}$$

Consider a case with N = 16 antenna phase elements. Assume that two jammers are present, one at an AOA of 28 degrees with an SNR of 45 dB and another at -23 degrees with an SNR of 33 dB. Accordingly an Array element is designed and the response of the array is viewed in MATLAB in presence of the jammers and in the absence of the jammers. Another set of jammers was considered at -5 degrees and at 5 degrees with similar SNR.

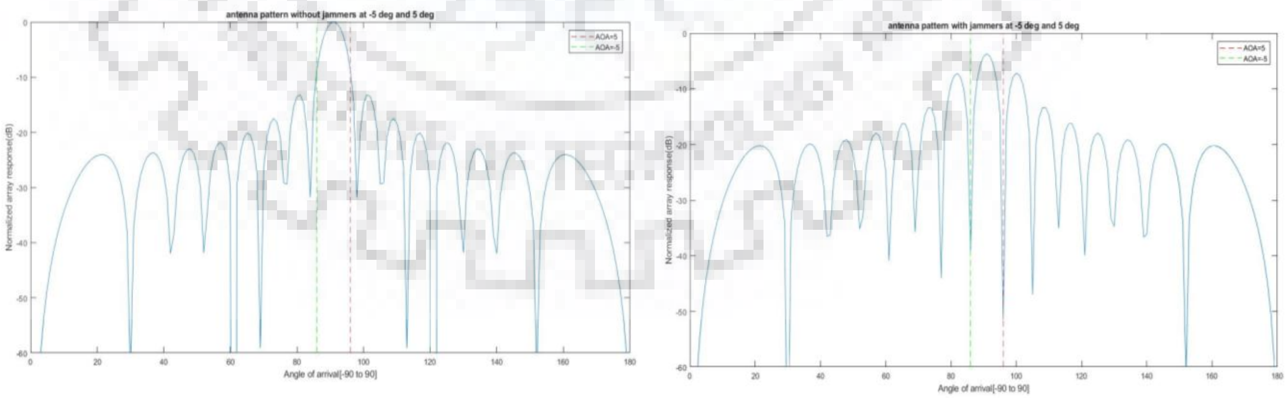



**Fig. 4.2. Adaptive Beam Forming with sources at -5 & 5 Degrees**

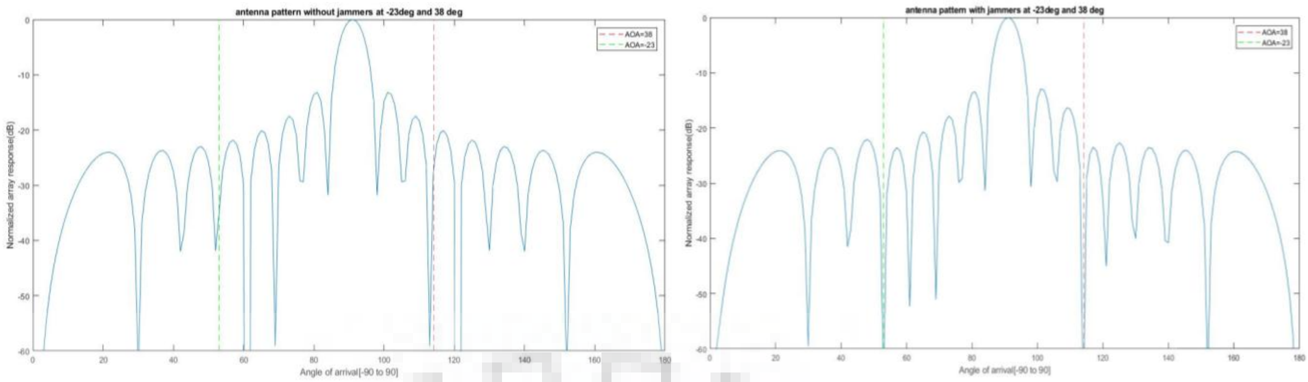



**Fig. 4.3. Adaptive Beam forming with sources at -23 & 38 Degrees**

## 4.2 Analytical Methods of DoA Estimation

The different variants of the Angle of Arrival estimation are in practice and are brought into the array processing depending upon the application and source information. The methods are used to measure the spectral estimation, the entropy of the system, maximum likely hood of the presence etc. The beam pattern and the excitation factor of the array are Fourier dependent. It can be said that the DoA estimation is the study of the spectral distribution of the signal as per the array. These various forms of the algorithms are used. The beam is circulated in all possible directions and the point of max power is noted. This is the measure of the Angle of Arrival of the source, as the interference noise is Gaussian and uniformly distributed. In this scheme, the entire expanse is searched and the direction of zenith power in the spectrum furnishes the source dispensation. In a streamline fashion, the variation adjustment factor *w* of the array is accredited with the mathematical entente:

$$y(t) = w^H x(t) \tag{44}$$

The aggregate power of N iterations of the processing tool can be manifested as:

$$P(w) = \frac{1}{N}\sum_{k=1}^{N} |\, y(t_k)|^2 = \frac{1}{N}\sum_{k=1}^{N} w^H x(t_k) x^H (t_k) w = w^H \hat{R} \tag{45}$$

Where $\hat{R}_{xx}$ is a two dimensional set of the inter element data of mutual coupling.

### 4.2.1 Conventional Beamforming using Bartlett's Algorithm

In this method the power spectrum of the arriving signal is studied by calculating a weight value for each steering vector. The steering vector $a(\theta)$ for a random angle can be enunciated as:

$$a(\theta)=\left[1\,e^{j\xi}\;e^{j2\xi}\;\cdots\cdots e^{j(N-1)\xi}\right] \tag{46}$$

where $\xi=-\frac{2\pi}{\lambda}d\sin\theta$

The weight vector calculation in normal form is denoted by:

$$w_n=\frac{a(\theta)}{\sqrt{a^H(\theta)a(\theta)}} \tag{47}$$

The mathematical dependency of power is given by:

$$P(\theta)=\frac{a^H(\theta)R_{xx}a(\theta)}{a^H(\theta)a(\theta)} \tag{48}$$

### 4.2.2 Minimum Variance Distortion Beamforming

This is one of the conventional beam forming techniques, which follows the likelyhood of the signal presence in a particular direction. During execution, it finds apex likelihood valuation of power at a acme and droping others as interference. The aim of this algorithm is to keep the incoming signal source identical in phase and amplitude and is achieved by maximising the signal to interference ratio. The mathematical denotion for dispensation of energy distribution is

$$P_{MV}(\theta)=\frac{1}{a_\theta^H R^{-1}a_\theta} \tag{50}$$

Where $a_\theta$ gives the measure of the steering vector and R denotes the dimesional set of interdependence of elements. In this method the line of sight for crest incoming power of the signal is earmarked and the beam is formed in that direction and the iterations are then run to make the angle accurate. This tehcnique is suitable incase of single source present as the algorithm makes the processing in the look up direction at any point of time. In case of multiple sources present, the accuracy in the readings may reduce as there are chances of contribution from the adjacent sources. The depiction of this constraint can be viewed as:

$$\min P(w) \text{ subject to } w^H a(\theta) = 1 \tag{51}$$

The value of the antenna weights at any given point of time is given by:

$$w = \frac{\hat{R}_{xx}^{-1} a(\theta)}{a^H(\theta) R^{-1} \hat{a}(\theta)} \tag{52}$$

The resulting power spectrum can be written as:

$$P(\theta) = \frac{1}{a^H(\theta) \hat{R}_{xx}^{-1} a(\theta)} \tag{53}$$

## 4.3 Subspace Based Techniques

A system is constituted of energy contributions. When a space is acted upon by a force, it distributes the space into inline and balance directions. The inline components contribute maximum for the desired result. Therefore, the inline components have more average energy level and the balance directions have lower average energy value. This is dividing the space into two sub spaces and is called Eigen. The higher sub space is signal component and the lower sub space is noise. This is the basis of these techniques for gaining better resolution. At any instance, the steering vector scanning the space is at 90 degrees to the noise sub space.

### 4.3.1 Multiple Signal Classification (MUSIC)

In this category of process, the sub space bifurcation is done with simplified manner of the system under investigation.

The area explored by this algorithm is segregated into signal heavy and noise heavy sub categories.

The relative phase delay direction analogous to the directional sources are quadratic to the noise contributors in the plane of operation. Once the plane of the noise contributors is obtained, in the balance area of operation, the quadratic relative phase delays are searched for. The peaks of the MUSIC energy distribution pattern in this remaining space are noted and are given by:

$$P_{MU}(\theta) = \frac{1}{a_\theta^H U_N} \tag{54}$$

Where $U_N$ is the rectangular array of M rows and M-K columns. The columns component of the array denotes the noise element contributors and $a(\theta)$ denotes the relative phase delay in the direction $\theta$. This algorithm has a very high capability to differentiate nearer values and it uses the quadratic property of the two space contributors. The random variable variance rectangular array is given by:

$$\hat{R} = E\left[xx^H\right] = AE\left[ss^H\right]A^H + E\left[nn^H\right] = A\hat{R}_{ss}A^H + \sigma_N^2 I \tag{55}$$

Where $\hat{R}_{ss}$ is the signal variable variance measure, $\sigma_N^2$ is the noise spread variance.

The MUSIC spectrum is given as:

$$P(\theta) = \frac{1}{|a^H(\theta) E_N E_N^H a^H(\theta)|} \tag{56}$$

### 4.3.2 Linear Prediction (LP) Method

In this method, two values of a particular sensor are taken. One value is the actual output value and the other is the estimated value. The estimated value is calculated by studying the nature of the sensor due to the adjacent sensor. The mean of both the values is calculated and it is set to minimum. The corresponding weight values are noted. The mathematical relationship for the relative factor and the energy spread is as:

$$\hat{w} = \frac{R^{-1}u_1}{u_1 R^{-1} u_1} \tag{58}$$

and

$$P_{LP}(\theta) = \frac{u_1^H R^{-1} u_1}{|u_1^H R^{-1} a_\theta|^2} \tag{59}$$

$u_1$ is a column vector which has the unity value for the sensor under calculation and the contribution from others is taken as zero.

CHAPTER 5

## 5. Results and Discussion/Analysis

The various algorithms have been studied during the course of the project and capability and accuracy in estimating the DoA of a arriving signal were compared. A signal set up was designed with following parameters and the algorithms executed and results obtained. The results have been analysed and the output pattern compared with the theoretical studies during the course of the paper. The following test parameters were considered for obtaining the various DoA algorithm results:-

(i) A uniform linear array of 10 elements.
(ii) Inter-element spacing of $\lambda/2$.
(iii) Algorithm processing instances of 200.
(iv) SNR of 10dB.
(v) Source of equal power of 10dB.
(vi) Carrier frequency of 1 MHz.
(vii) Source angles of $\theta1$=-20, $\theta2$=30 and $\theta3$=60
(viii) The spacing of 10cm between each element.

The following results obtained:-

(i) Bartlett's Algorithm

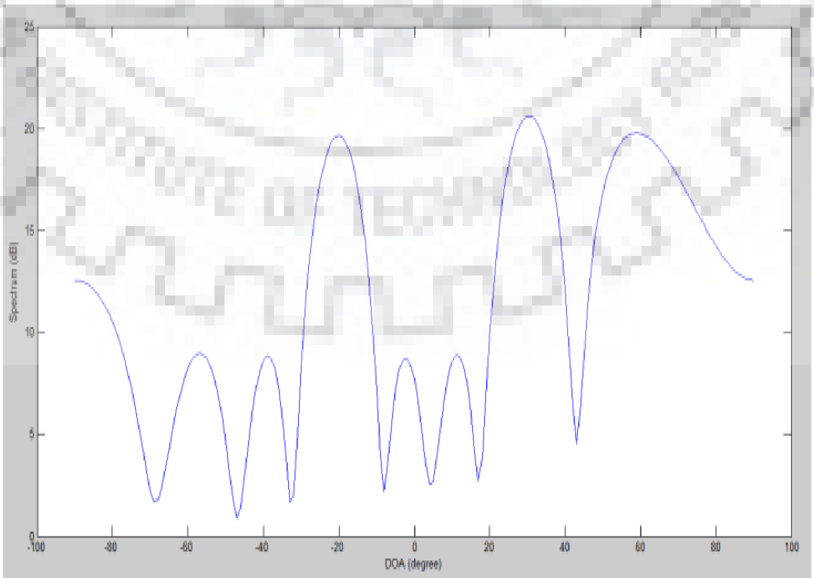



**Fig 5.1. Performance Analysis of Classical Beam Forming**

(ii) MVDR Algorithm

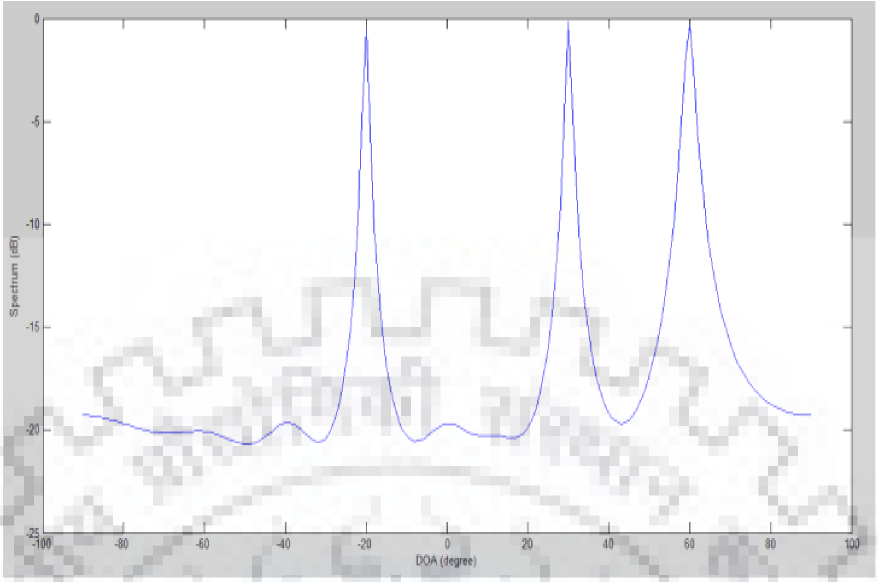



**Fig 5.2. Performance Analysis of Minimum Variance Distortion Less Response Beam Forming**

(iii) MUSIC Algorithm

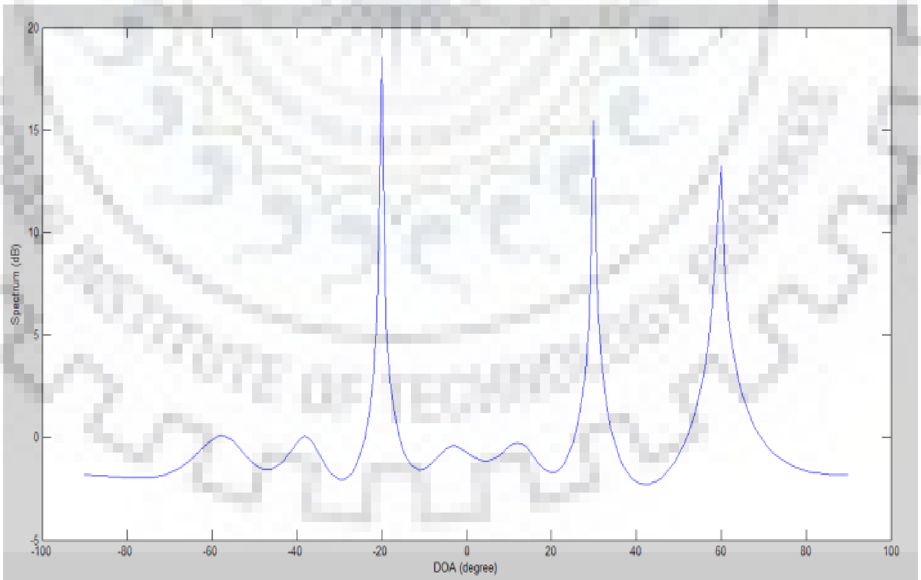



**Fig 5.3. Performance Analysis of MUSIC Beam Forming**

(iii) Linear Prediction Algorithm

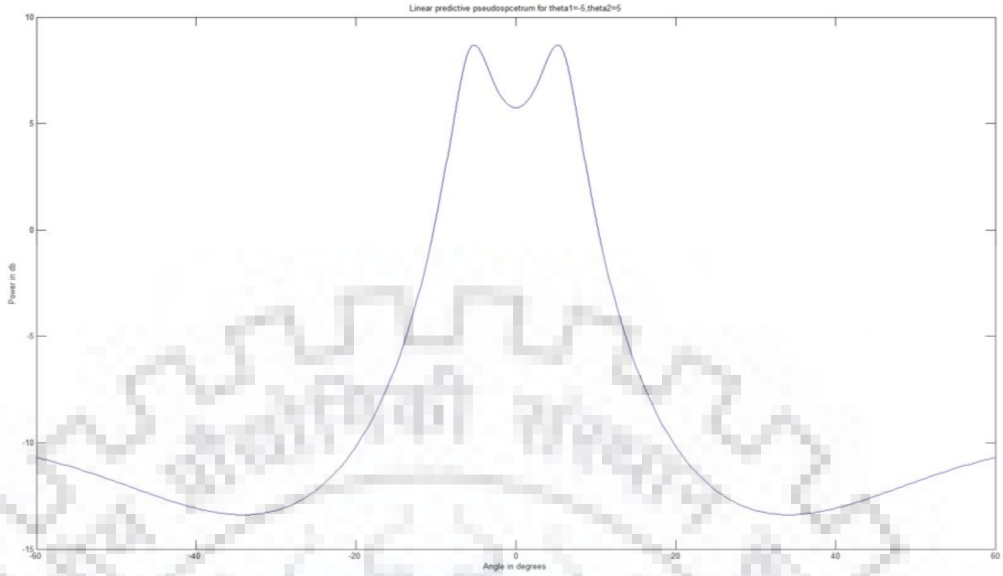



**Fig. 5.4 Linear Prediction Performance Analysis**

It is seen that there are various parameters both of the antenna array and the signal that decide in giving the final accurate result for the signal DoA. Two test exercises were carried out to compare the performance of algorithms by varying the performance parameters.

TEST EX 1

(a) Response of BARTLETT's Algorithm on changing the number of snap shots from 1000 to 3000.

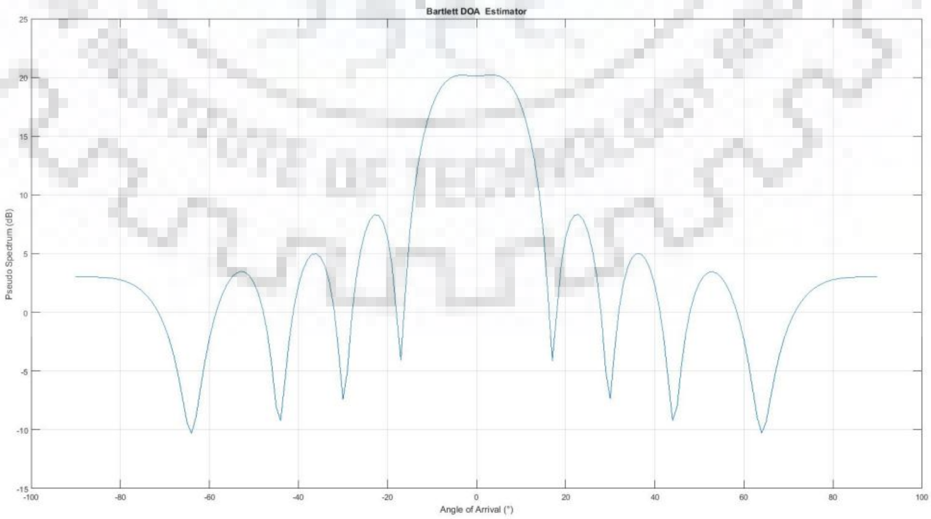



**Fig. 5.5. L=1000**

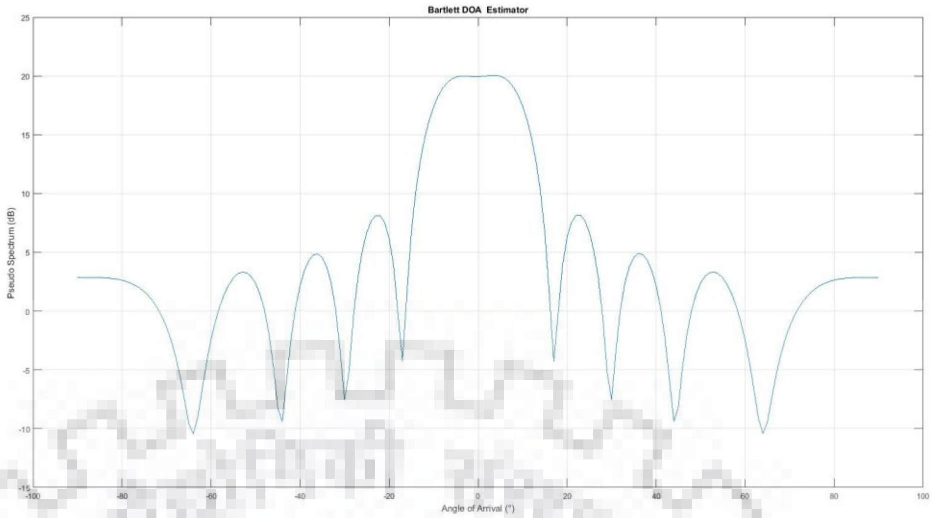



**Fig. 5.5. L-3000.**

(b) Response of BARTLETT's Algorithm on changing the number of elements N=10, N=100 and N=300.

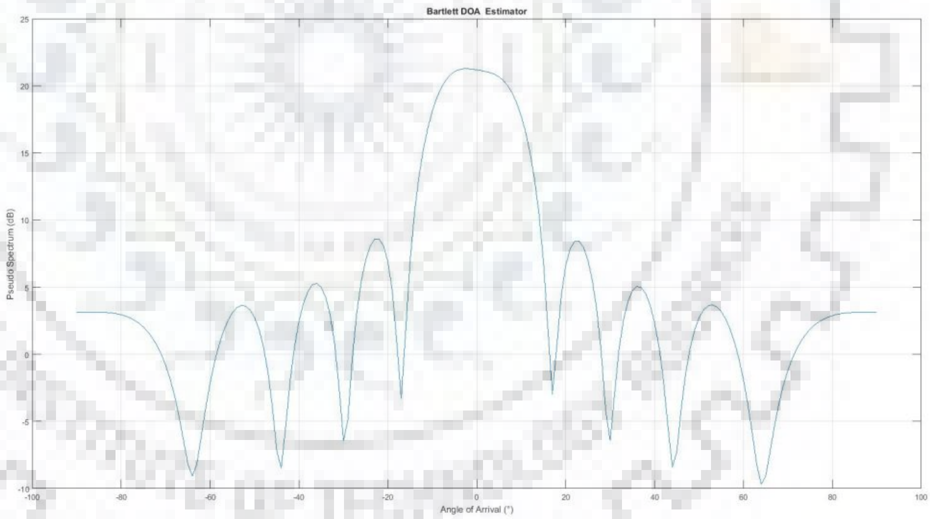



**Fig. 5.6. N=10**

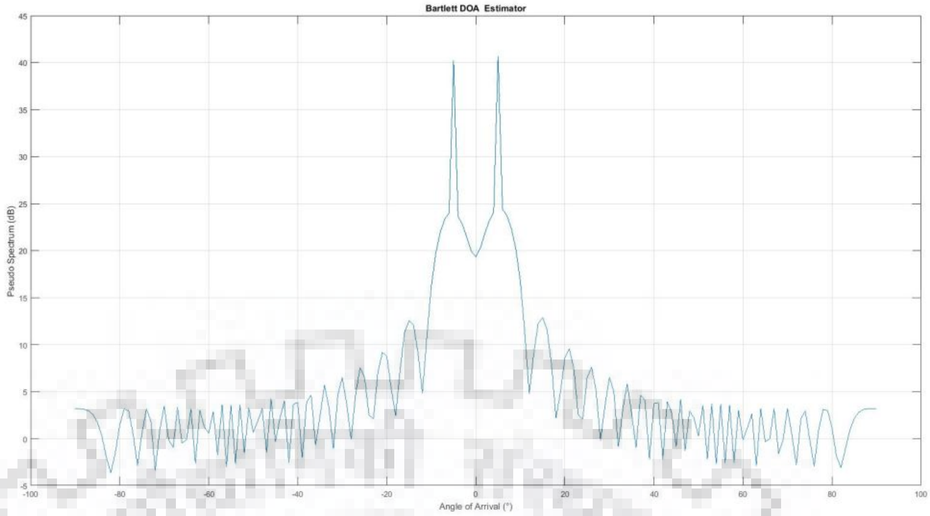



**Fig. 5.6. N=100**

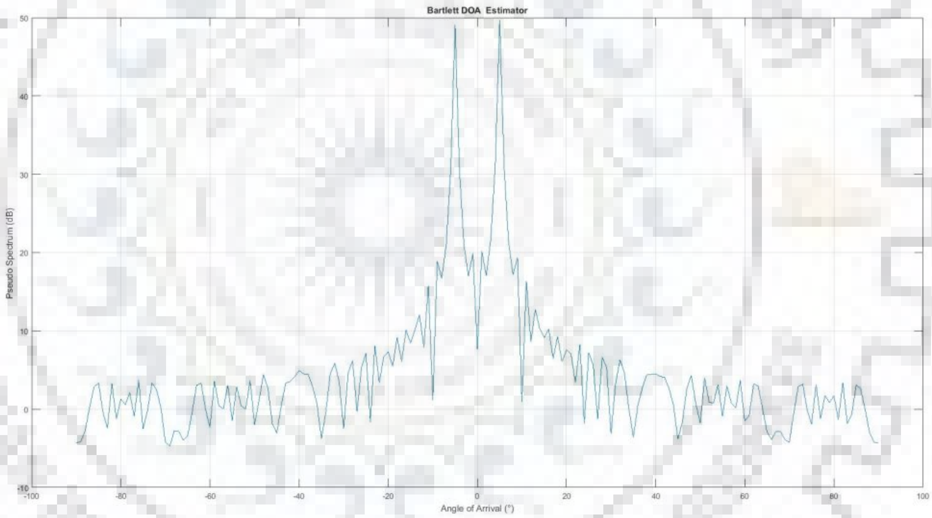



**Fig. 5.6. N=300**

(c) Response of BARTLETT's Algorithm on changing the SNR from 20dB to 45 dB.

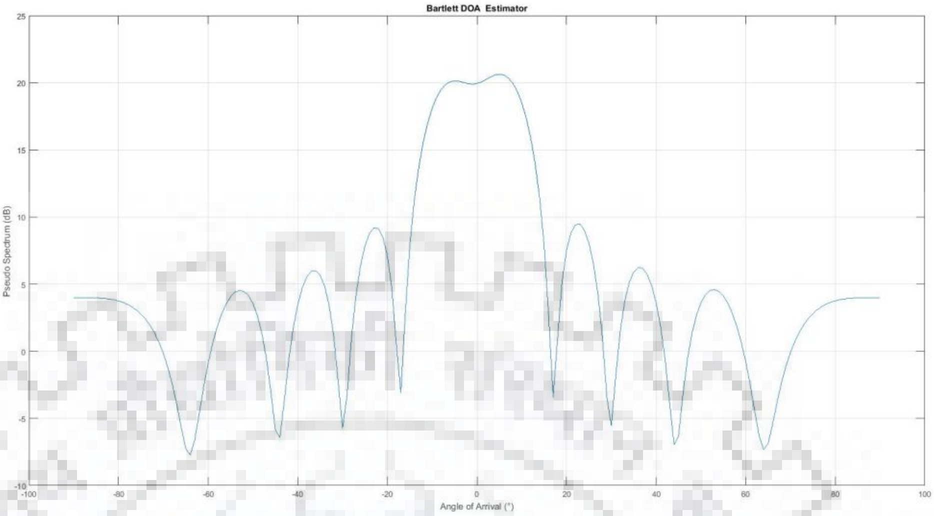



**Fig. 5.7. SNR of 20 dB**

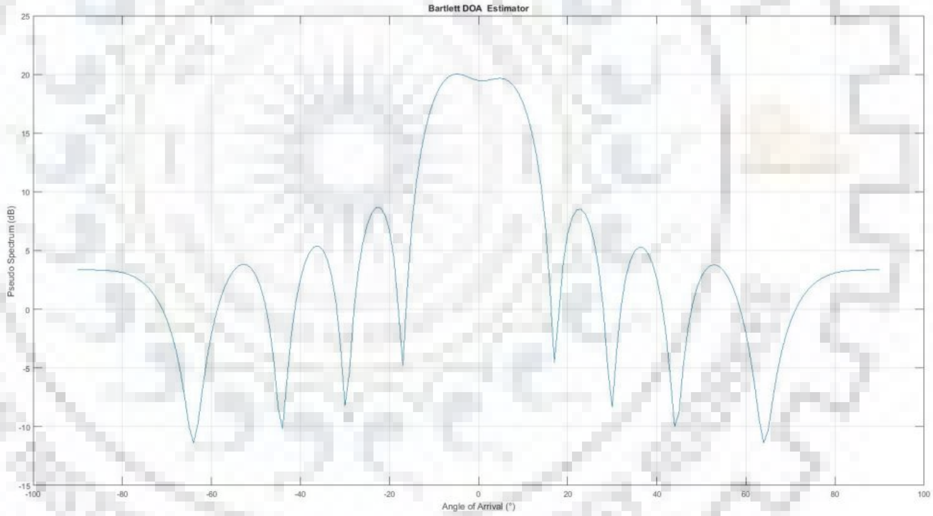



**Fig. 5.7. SNR of 45dB**

(d) Response of MUSIC Algorithm on changing the number of snap shots from 600 to 900.

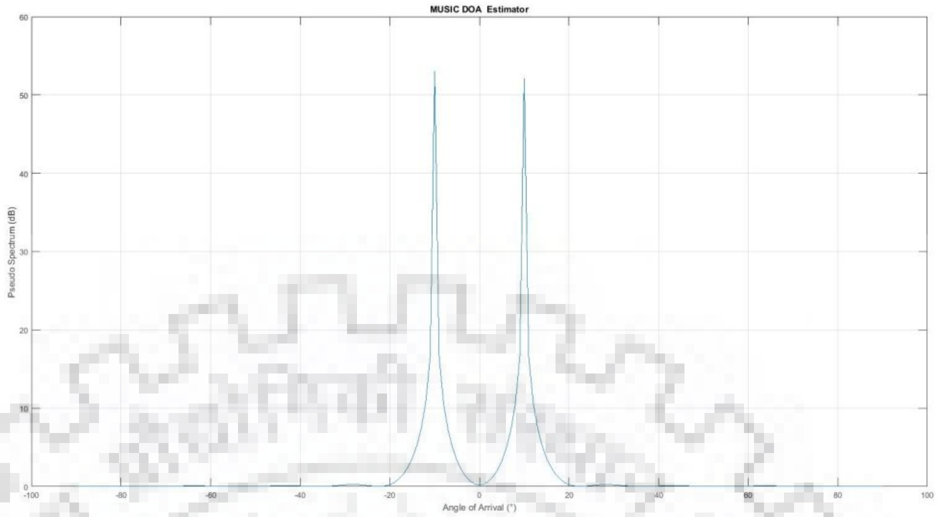



**Fig. 5.8. L=600**

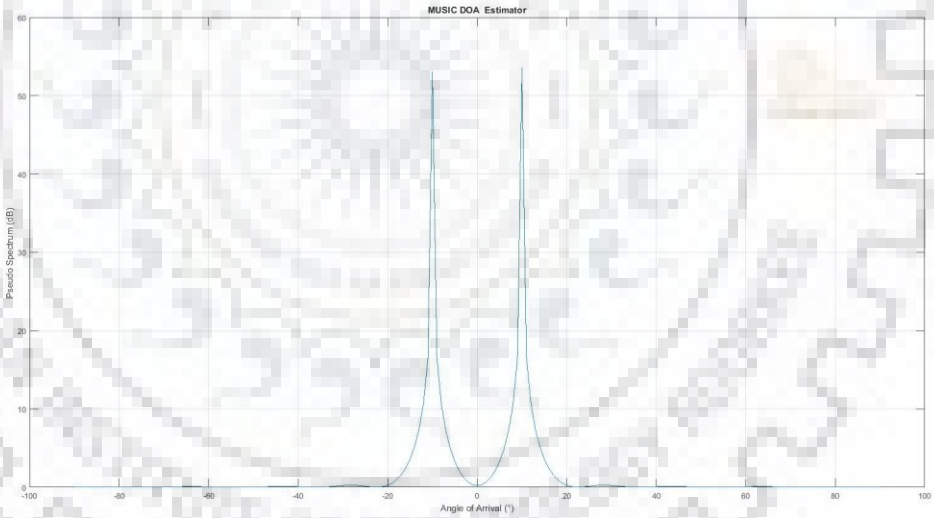



**Fig. 5.8. L=900**

(e) Response of MUSIC Algorithm on changing the number of elements from 10, 50 and 100.

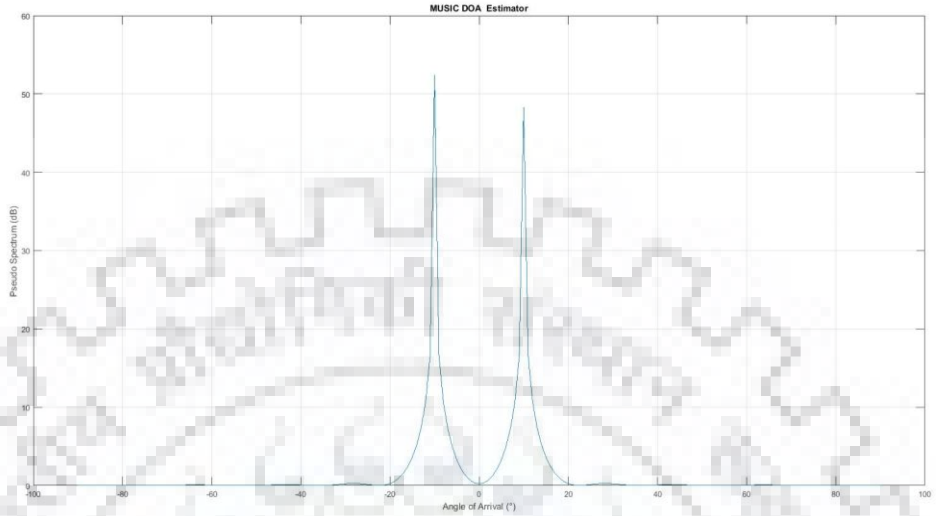



**Fig. 5.9. N=10**

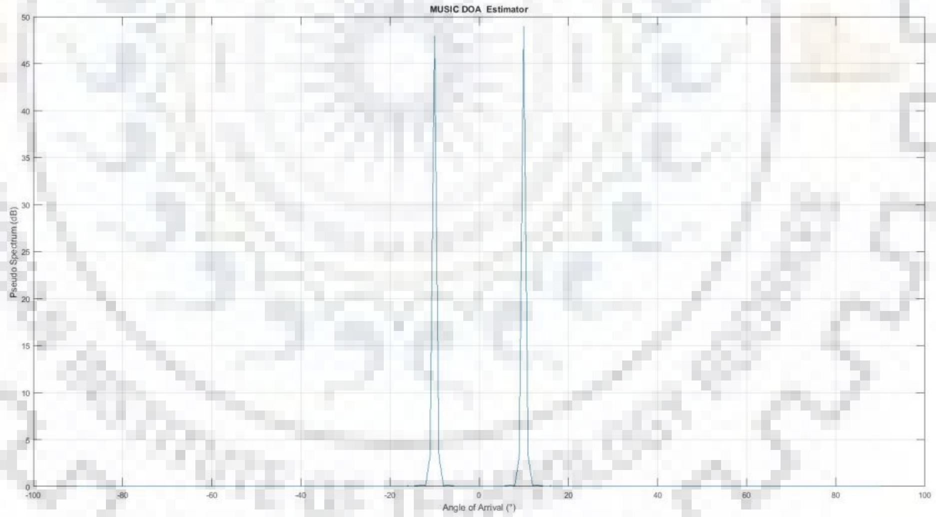



**Fig. 5.9. N=50**

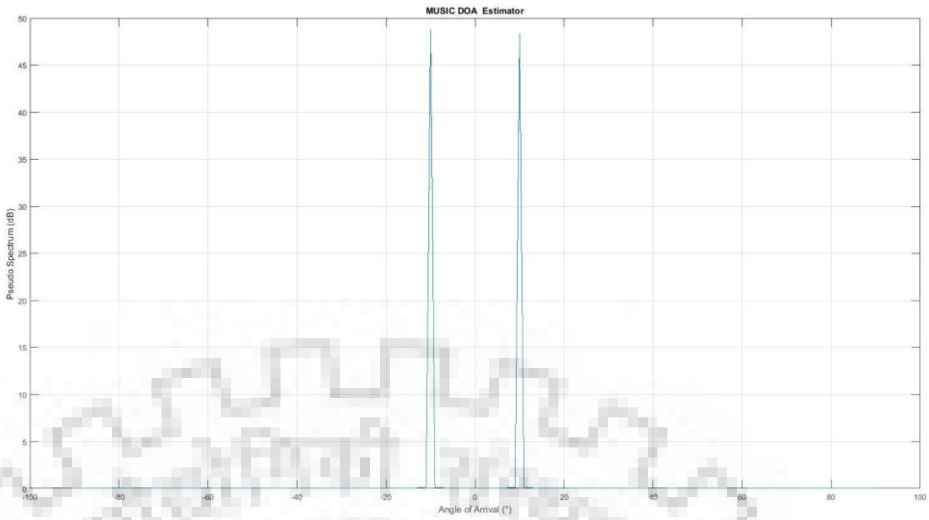



**Fig. 5.9. N=100**

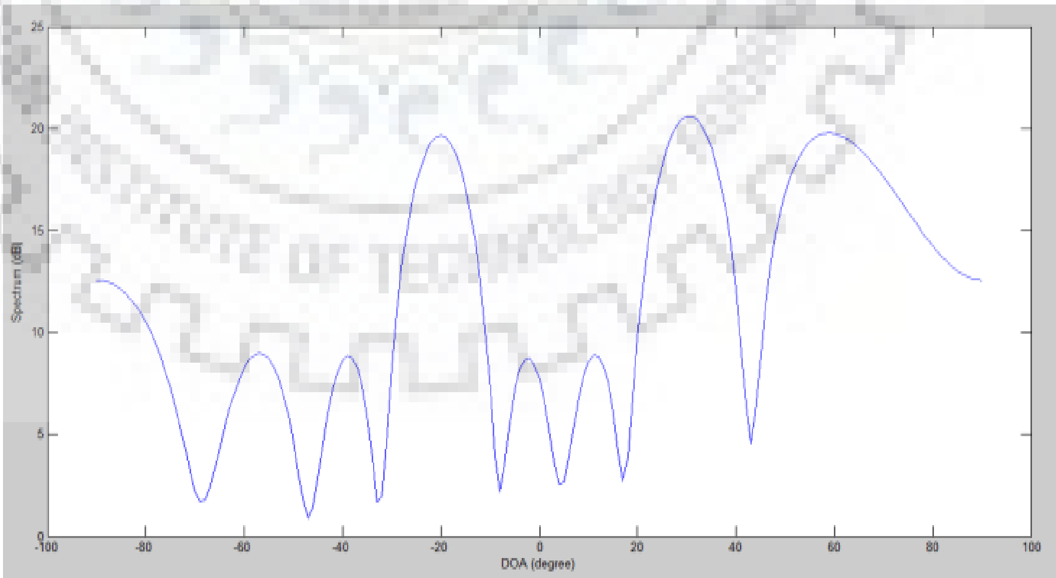
TEST EX 2. In this exercise the algorithms were again tested for varying parameters and the results compared. The following were the parameters for testing.

(i) SNR of the signal increased from 0 dB to 50 dB.

(ii) Number of snap shots increased from 10 to 10000.

(iii) Number of antenna elements increased from 10 to 100.

a.



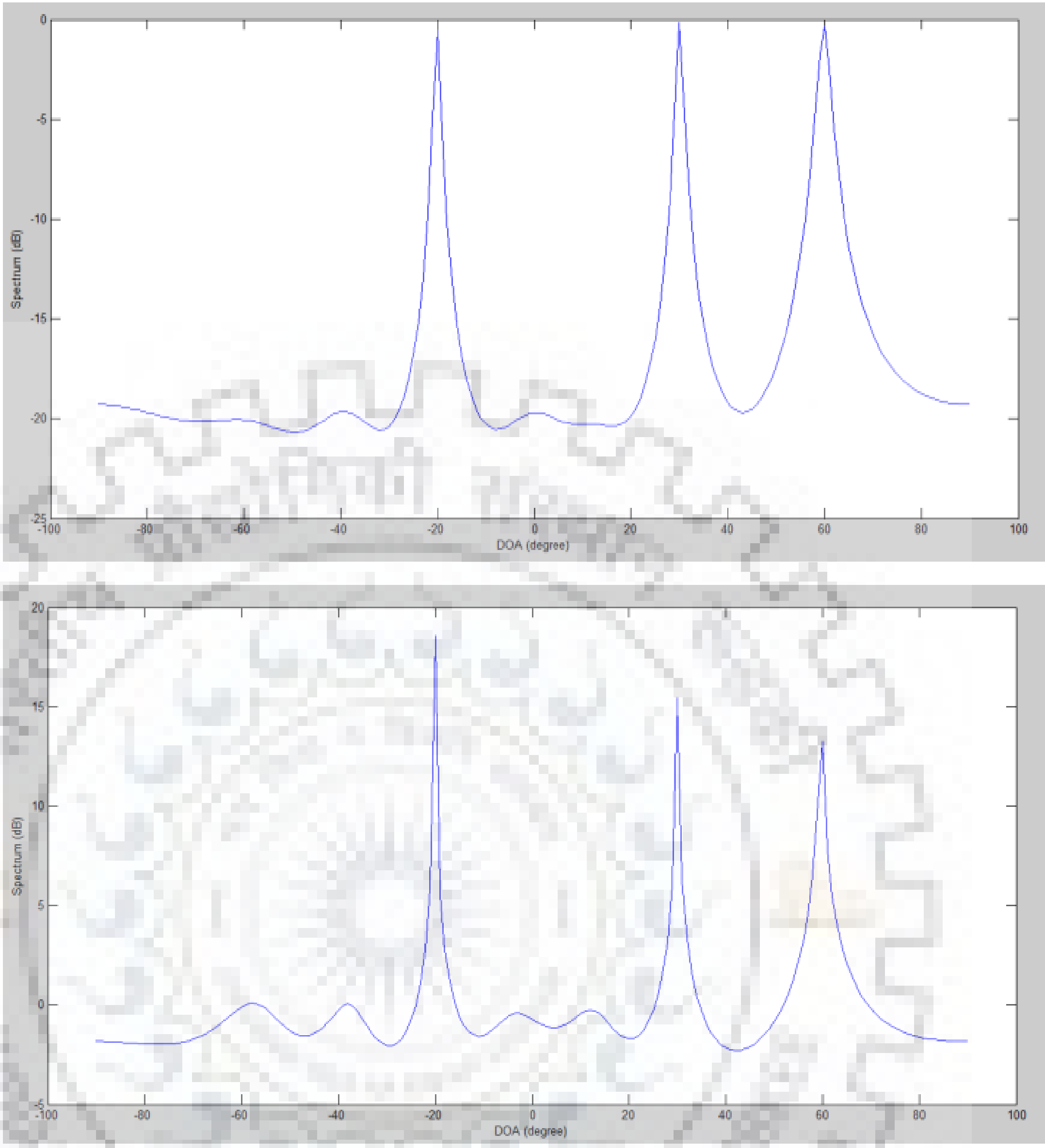



**Fig. 5.10. Performance Comparison of Algorithms**

(i) The above results show the performance analysis of the algorithms.

(a) The response of MVDR improves due to constrained weights.

(b) The response improves further in case of MUSIC algorithms due to the Eigen value decomposition.

b.

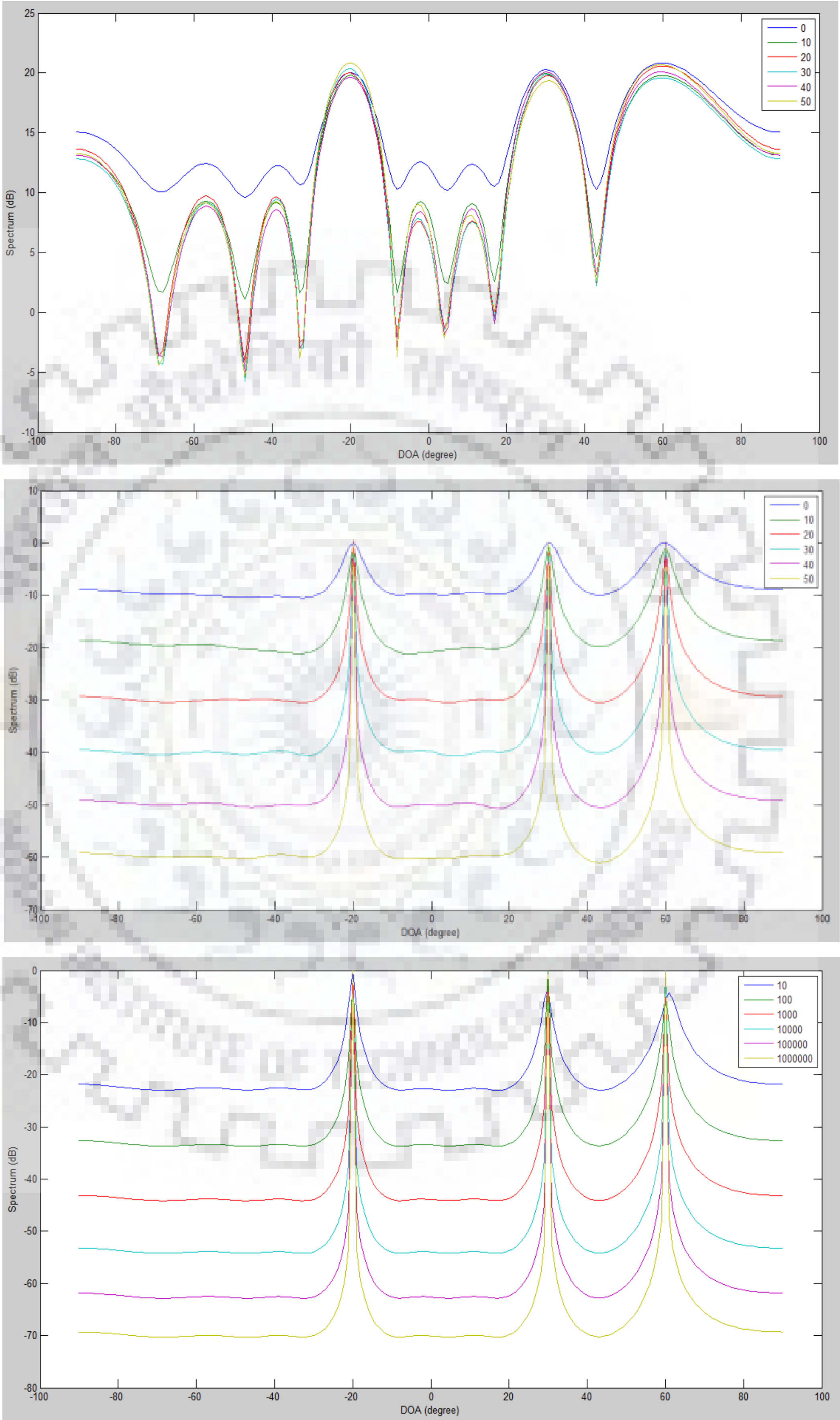



**Fig. 5.11. Performance Comparison on varying SNR**

(i) The above results show the performance of the algorithms when the SNR is varied from 0 to 30 dB.

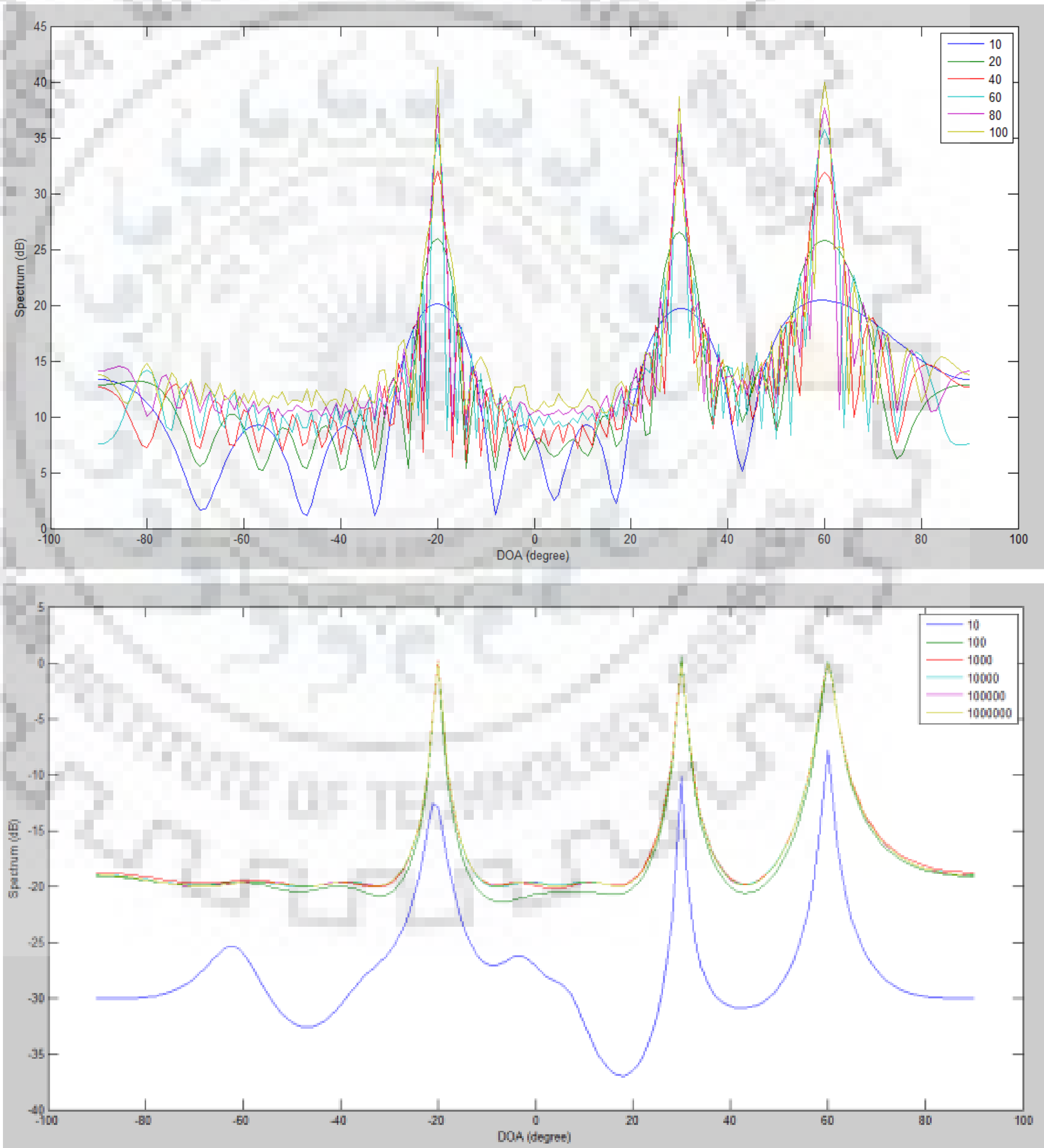
(a) By elevating the signal pin of level, the energy spread varies diversely with amiss veracity.

(b) As the signal pin of level is increased, there is a decrease in frequency spread level.

(c) We get a callous response for lower value of signal ratio.

(d) The ability to demarcate takes a rise as we use high power signals.

**c.**



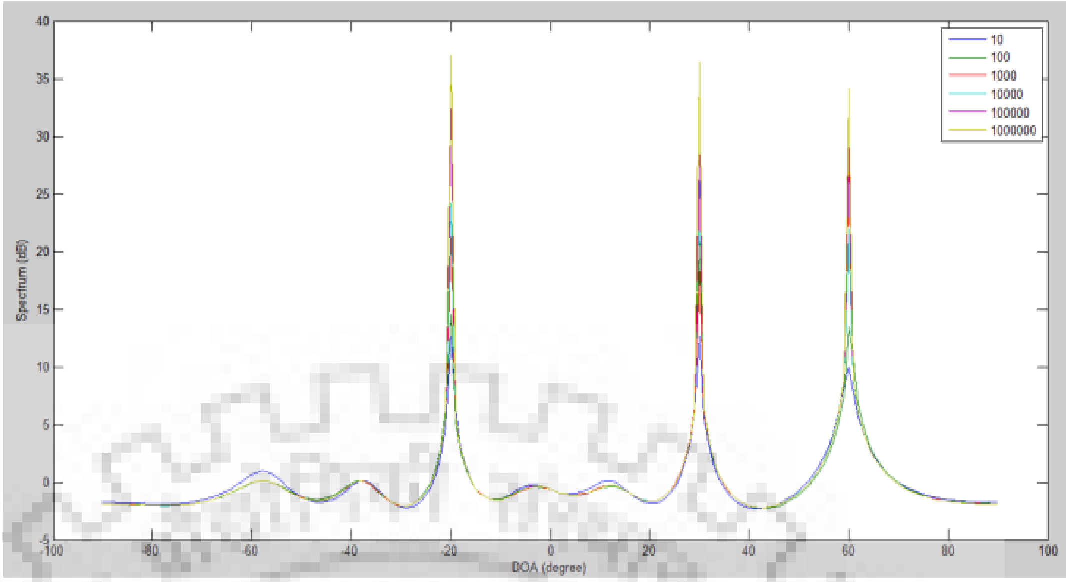



**Fig. 5.11. Performance Comparison on varying No of Snap Shots**

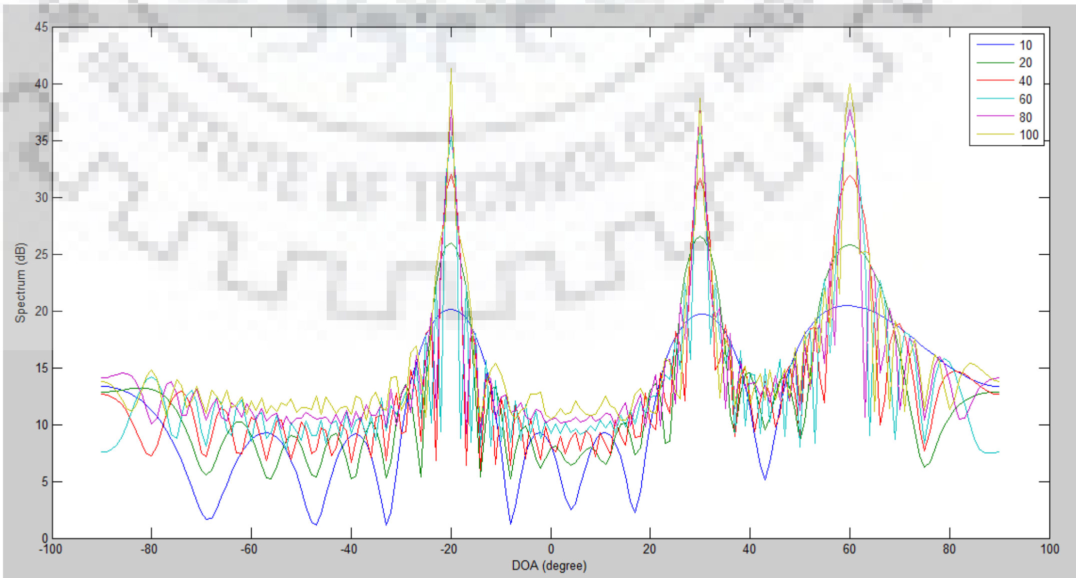
(i) The above results show performance of the algorithms on varying the snapshots from 10 to 10000.

(a) DBF changes with diminished accuracy.

(b) For MVDR and MUSIC, as the processing is on individual parameter, the energy spread increase as we increase the run frequency of the instructions.

(c) The accuracy improves for MVDR and MUSIC.

d.



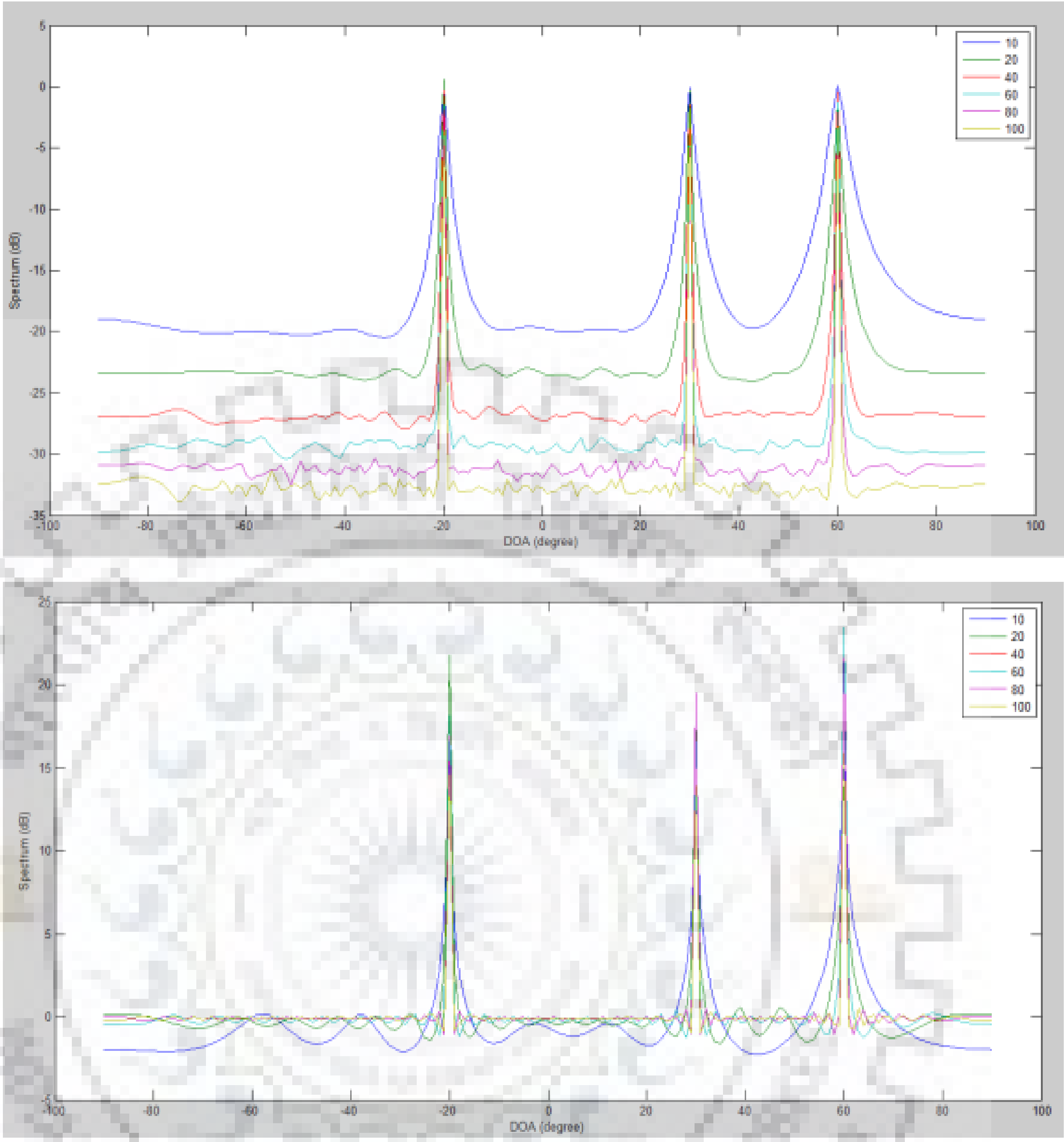



**Fig. 5.11. Performance Comparison on varying No of Array Elements**

(i) The above results show the performance of the algorithms on varying the number of elements from 10 to 100.

(a) As we increase the excitation feeds, the thinner the detection accuracy.

# CHAPTER 6

## Conclusion

The accurate estimation of the DoA, requires finer processing of the signal data. The accuracy degrades in the homogenous environment where different interfering sources are present. A highly accurate technique for DoA estimation, which performs in the correlated environment is the use of NN based networks. In this technique, the values of the received power from each beam and the mapping of the same with the help of NN networks are used. The signal is fed by a 8x8 Butler Matrix.

In some cases, the uniform illumination is preferred due to the orthogonal property of the beams. The sector beam can be used to serve the similar communication channels and can thus enhance the methods efficiency. With the use of sector beam the covet signal's DoA can be extracted with a accuracy to fraction level, even if the power content is 6 dB down from all of the 39 intrusive signals.

As the SeIR gets lower, the coverage gets feeble at the edges, leading to failed DoA estimation of the signal. The method proposed in chapter 5 namely DoA estimation techniques in a failed antenna array, is based on N-MUST algorithm. DoA is estimated in two stages-Detection Phase and DoA Estimation Phase. Regions at angular locations from $-60^0$ to $60^0$ with respect to antenna array are considered for the purpose of DoA Estimation. This area of $120^0$is divided into 12 regions each of width $10^0$. In the first stage, corresponding to each small area we had employed two separate NNs-one for detecting, whether any sources are present in that sector or not and the other one for estimating the exact location of the source, if the sources is present in that sector. So, in total 12 NN were employed in detection phase and another 12were used in DoA estimation phase. This algorithm was used to estimate the direction of arrival of three radiating sources. The antenna array used comprises of 10 elements. Neural Network employed in detection and estimation phases were trained considering all possible cases in which a maximum of two elements in the antenna array can suffer faults. The proposed scheme does not need the knowledge of the position of failed array antenna elements and work well for both correlated and uncorrelated sources.

The output of DoA estimation stage was different sectors. Root mean square error between the actual DoA and that estimated from the network varies for different sectors.

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