A

Thesis

On

Interference Reduction in CDMA Systems using Antenna Arrays

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

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In
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by

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Certificate

I, Anisha, hereby certify that the work which is being presented in this thesis entitled **"Interference Reduction in CDMA systems using Antenna Arrays"** by me in partial fulfillment of the requirements for the award of degree of Master of Engineering in Electronics and Communication from Thapar Institute of Engineering and Technology (Deemed University), Patiala, is an authentic record of my own work carried out under the supervision of Mr. Rajesh Khanna.

The matter presented in this thesis has not been submitted in any other University / Institute for the award of Master of Engineering.

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This is certified that the above statement made by the candidate is correct to the best of my knowledge

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The real sprit of achieving a goal is through the way of excellence and austerous discipline. I would have never succeeded in completing my task without the cooperation, encouragement and help provided to me by various personalities.

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Abstract

The field of wireless communications is growing at an explosive rate, covering many technical areas. The deployment of cellular systems is a success and as the subscriber population continues to grow at a rapid pace, service providers may get capacity problems due to limited available frequency spectrum. Consequently, service providers are forced to find methods of enhancing the coverage and the capacity of their cellular networks. A promising future method suggested is to utilize adaptive antennas, which has also been recognized as one potential economic approach. Adaptive base station antennas have been proposed as a means to achieve the requested longer range and higher capacity in cellular systems.

In WCDMA, there is large number of interferers present in the system due to frequency reuse factor of one. The large numbers of interferers in these systems require a beamforming technique and other methods like null forming that would efficiently suppress the power in the undesired direction at the same time maximizing the power in the desired direction. For these systems side lobe adjustment and null forming would be a simple solution towards suppressing intercell and intracell interference and hence improving CIR performance and placing the nulls in the direction of individual interferers.

In this dissertation, a beamforming algorithm is analyzed for flexible side lobe adjustment. The algorithm places a very low side lobe level over a large width in the beam pattern. The convergence of this algorithm is fast and requires only two to three iterations. This algorithm can also form nulls in the desired direction. This beamforming algorithm is suitable for uplink and downlink since it is based on the DOAs estimated in uplink. The null forming method, based on constrained mean square approximation is discussed, which forms the null in the desired direction.

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List of Abbreviations

BER	Bit Error Rate
BS	Base Station
CCI	Co-channel Interference
CIR	Carrier Interference Ratio
CDMA	Code Division Multiple Access
DOA	Direction of Arrival
ESLL	Equal Sidelobe Level
FDMA	Frequency Division Multiple Access
MMSE	Minimum Mean Square Error
MS	Mobile Station
MV	Minimum Variance
MVDR	Minimum Variance Distortion less Response
MAI	Minimum Access Interference
MSIR	Minimum Signal to Interference Ratio
QoS	Quality of service
SIR	Signal to Interference Ratio
SDMA	Space Division Multiple Access
TDMA	Time Division Multiple Access
ULA	Uniform Linear Array
WCDMA	Wideband code division multiple access

Chapter 1
Introduction

1.1 Background

The demand for wireless communications services is growing at an extensive rate all over the world. The intensive development and wide application of new generations of personal communication systems and wireless communication systems have increased the need of new antenna designs [1]. As the wireless communications networks expand, the number of both unwanted directional interferences and strong nearby sources increase, which degrade system performance. Optimal antenna arrays play an important role in the improvement of communications systems by providing increased coverage through antenna gain control and interference rejection [2,3]. All mobile communication systems are interference limited. So carrier interference ratio (CIR) is an important parameter in mobile communication. There are various techniques to improve CIR in mobile communication.

In many wireless communications systems, the carries interference (CIR) ratio is improved by using multiple nulls in the direction of interferers while maintaining omni directional coverage in the direction of network users. The nulls in the radiation pattern may be used to reduce the interference from strong nearby sources as well as co-channel interferes by introducing nulls in the direction of surrounding communication systems.

1.2 Evolution of Antenna System In Wireless Communication

The field of wireless communications is growing at an explosive rate, covering many technical areas. The deployment of cellular systems is a success and as the subscriber population continues to grow at a rapid pace, service providers may get capacity problems due to limited available frequency spectrum. In traditional cellular systems the base station, having no information on the position of mobile units, is forced to radiate the signal in all direction, in order to cover the entire area of the cell. This entails both a waste of power and the transmission, in the directions where there are no mobile terminals to reach, of a signal which will be seen as interfering for co-channel cells, i.e. those cells using the same group of radio channels. Analogously, in reception, the antenna picks up signals coming from all directions, including noise and interference. Consequently, service providers are forced to find methods of enhancing the coverage and the capacity of their cellular networks.

For a large geographical coverage a large number of mobile transceivers must be supported, the region is divided in a large number of cells [4]. This allows the same carrier frequency to be reused in different cells. A spatial distance to reduce the level of interference separates the signals at the same carrier frequency. Unfortunately, this can be a time consuming and expensive process, since building new cellular sites also includes finding and acquiring suitable base station site locations and extending the backbone infrastructure. Sectorization is one method of increasing capacity, but with associated tradeoffs in trunking efficiency and handoff rates. Sectorization has already been utilized to its practical limit in many deployed cellular systems. In the existing cellular systems, 60^0 and 120^0 sectorized cells are used [5] as shown in Figure 1.1.

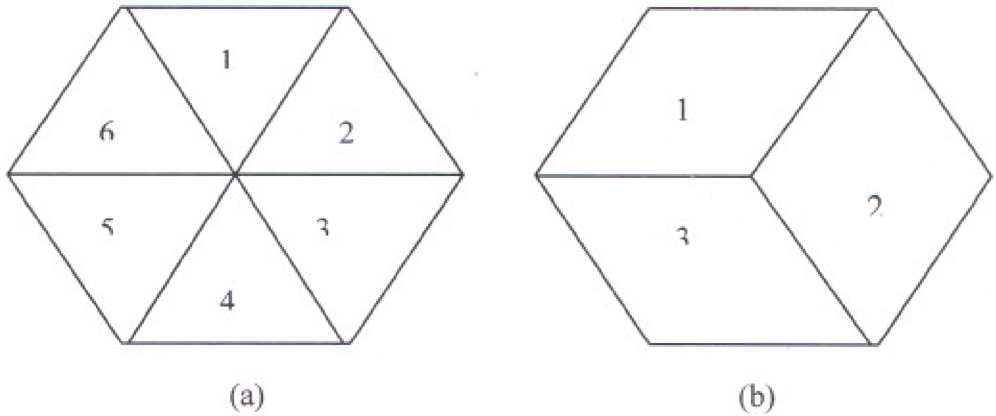


Figure 1.1: (a) 60^0 sectoring; (b) 120^0 sectoring

Another method of increasing capacity is the primitive form of SDMA. SDMA is based on deriving and exploiting information on the spatial position of mobile terminals. In particular, the radiation pattern of the base station, both in transmission and reception, is adapted to each different user so as to obtain, as shown in Figure 1.2, the highest gain in the direction of the mobile user. Simultaneously, radiation nulls shall be positioned in the directions of interfering mobile units. This behaviour is just defined "null steering" [6]. This requires the capability to carry out spatial filtering, which can be obtained by using, at the base station, an adaptive antenna array.

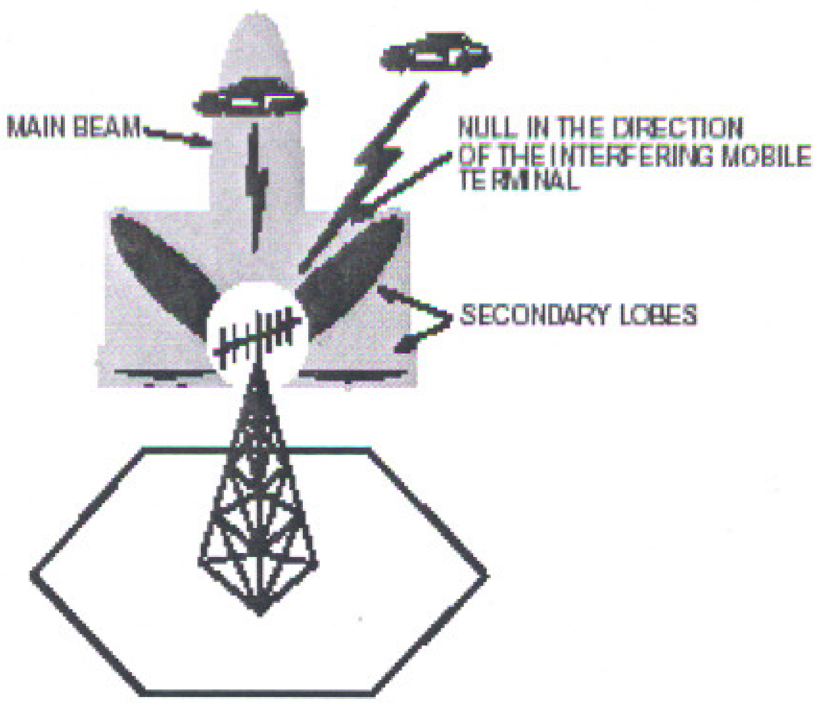


Figure 1.2 - Radiation beam pattern adapted for a single user

The use of an antenna array at the base station allows to introduce the SDMA technique, whose main advantage is the capability to increase system capacity, i.e. the number of users it can handle. This increase can be obtained in two different ways [7] i.e. reduction in co-channel interference and spatial orthogonality.

Reduction in co-channel interference: The reduction in the level of co-channel interference between the different cells using the same group of radio channels is obtained, by minimizing the gain in the direction of interfering mobile units. This technique allows us to reduce frequency re-use distance and cluster size. In this way, each cell can be assigned a higher number of channels.

Spatial orthogonality: In conventional access techniques, orthogonality between signals associated with different users is obtained by transmitting them in different frequency bands (FDMA, Frequency Division Multiple Access), in different time slots (TDMA, Time Division Multiple Access) or using different code sequences (CDMA, Code Division Multiple Access). Using an antenna array, it is possible to create an additional degree of orthogonality [8] between signals transmitted to and from different directions. It is thus possible to assign the same physical channel to several mobile units, when the angles at which they are seen by the base station are sufficiently separated. The result is an increase in the number of available channels, since the same physical channel, for example the same carrier in a FDMA system or the same time slot in a TDMA system, can be subdivided into multiple spatial channels, each of which is assigned to a different user.

In addition to the opportunity to increase system capacity, the SDMA technique has additional characteristics making its introduction in a mobile radio system advantageous [7]. In particular, it is possible to exploit the higher receive gain offered by an antenna array with respect to an omnidirectional case, to allow mobile units to transmit at reduced power, and therefore lower consumption. At equal power, gain can be exploited to extend cell size. This is useful when it is necessary to cover vast surface areas (typically rural areas), characterised by a low mobile radio traffic density, with a limited number of base stations. Moreover, there is a reduction of the multipath fading effects, by carefully choosing weight vector w, it is possible to select only one or more multiple paths, which are added coherently, thus avoiding destructive interference and limiting received power reduction [9].

SDMA technique requires an array composed of more antennas; in fact spatial orthogonality is exploited by eliminating, through the use of spatial filtering, intra-cell co-channel interference, which is due to mobile units belonging to the same cells and using the same channel as the mobile unit in question. The power level at which the base station receives signals transmitted by these mobile units is comparable with that of the useful signal. It is therefore necessary for the radiation pattern associated with the desired user to have, in the directions of these interfering units, very deep nulls, to suppress co-channel interference from other cells. This is shown in Figure 1.3, where radiation patterns for two mobile units sharing the same channel are depicted. To obtain such a selective response, it is necessary for the antenna array to be highly directive, and therefore for the number of antennas to be high. This increase in the number of antennas is not only difficult to accomplish, but also presents control algorithms with high computational complexity, which results in lower adaptation speed and therefore in problems handling fast-moving mobile units.

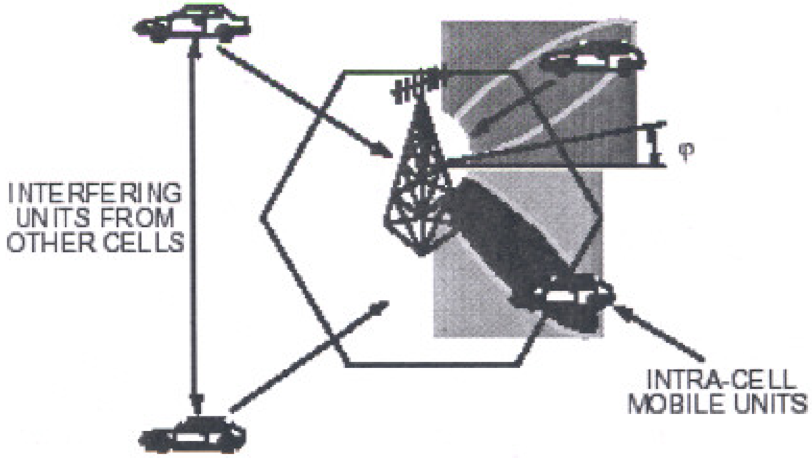


Figure 1.3 -Radiation patterns associated with two users sharing the same channel. Deeper nulls must be aimed in the direction of the intra-cell interfering unit.

Besides, in a FDMA/TDMA only a limited number of interfering mobile units are present for each users, and their signals, in the SDMA technique, must be carefully eliminated by creating nulls in the corresponding directions of arrival. With the CDMA technique, since all mobile units share the same band, the number of potential interfering units is very high, certainly higher than the number of antennas in the array, i.e. the number of degrees of freedom of the adaptive system. Interferent units can also be considered uniformly distributed around the base station. As a consequence, the behaviour of the radiation pattern adaptation system is no longer of the null steering type but instead, as shown in Figure 1.4, the main beam is simply pointed in the direction of the desired mobile unit [10,11]. In this way, the reduction in interference level will be only partial. Observe however that, as it is no longer necessary to put nulls in the direction of the interfering units with critical precision, the adaptation system actually requires less complexity.

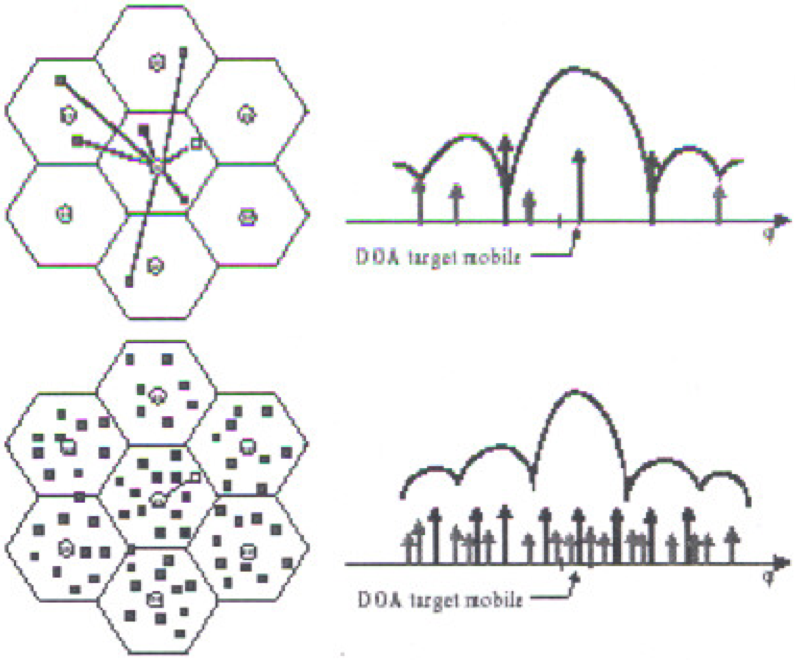


Figure 1.4 - Radiation beam pattern adaptation in SDMA for a FDMA/TDMA system (upside) and for a CDMA system. In this case there is no "null steering".

A promising future method suggested is to utilize Adaptive Antennas, which has also been recognized as one potential economic approach. Adaptive base station antennas have been proposed as a means to achieve the requested longer range and higher capacity in cellular systems. For established systems, Adaptive Antenna techniques can make use of existing cell sites, thus eliminating the costly step of deploying new sites for capacity enhancement.

1.3 Objective

- To study independent angular steering of each zero of the directional pattern for a linear array.
- To design an adaptive antenna array with a new technique having features like
  - Low Sidelobes with Minimum Beam width.
  - Manual error control.
  - Flexibility .
  - Equal side lobes.
  - Fast convergence.
  - Null in the direction of interferers.
- To simulate the increase in CIR by reduction in interference power achieved using above technique.

1.4 Literature Survey

In mobile communication Wideband direct sequence code division multiple access (WCDMA) was accepted as a wireless access scheme for 3G systems. In this same frequency spectrum is shared through all cells simultaneously, as opposed to TDMA. Thus in a WCDMA system all transmitted signals turn out to be disturbing factors to all other users in the system in the form of interference. One of key features in a 3G is a high data rate. For a high data rate, a lower BER and smaller spreading factors are required. Thus, higher transmitting power at a base station is necessary, which results in increased interference in the cell. The main source of interference is coming from other user's signals within the same cell known as intra-cell interference. Another source of interference is coming from adjacent cells inter-cell interference, which can have a substantial impact on the performance [12]. Thus, in WCDMA systems multiple access interference (MAI) is the major cause of transmission impairment. There are different methods to reduce the interference. Antenna arrays with steer able low side lobes can reduce interference in WCDMA can increase the system capacity and array performance. Techniques to reduce this interference are adaptive antenna array and there has been great deal of interest in reducing multiple access interference through use of beam forming to improve the capacity and the performance of CDMA based systems.

Array beam forming techniques exist that can yield multiple, simultaneously available beams. The beams can be made to have high gain and low side lobes, or controlled beam width. Adaptive beam forming techniques [13] dynamically adjust the array pattern to optimize some characteristic of the received signal. In beam scanning, a single main beam of an array is steered and the direction can be varied either continuously or in small discrete steps. Antenna arrays using adaptive beam forming techniques can reject interfering signals having a direction of arrival different from that of a desired signal. Multi-polarized arrays can also reject interfering signals having different polarization states from the desired signal, even if the signals have the same direction of arrival. These capabilities can be exploited to improve the capacity of wireless communication systems. An array consists of two or more antenna elements that are spatially arranged and electrically interconnected to produce a directional radiation pattern. The interconnection between elements, called the feed network, can provide fixed phase to each element or can form a phased array. In optimum and adaptive beam forming, the phases (and usually the amplitudes) of the feed network are adjusted to optimize the received signal. The geometry of an array and the patterns, orientations, and polarizations of the elements influence the performance of the array. Beam forming is just what the name sounds like, no pun intended. Beam forming is the process of trying to concentrate the array to sounds coming from only one particular direction. Spatially, this would look like a large dumbbell shaped lobe aimed in the direction of interest. Making a beam former is crucial to meet one of the goals of our project, which is to listen to sounds in one direction and ignore sounds in other directions. The best way to not listen in 'noisy' directions is to just steer all energy towards listening in one direction. This is an important concept, because it is not just used for array signal processing, it is also used in many sonar systems as well.

Adaptive beamforming has been a subject of considerable interest for more than three decades. There are a number of textbooks and tutorial papers devoted to general concepts and applications of adaptive beamforming. In addition numerous papers and articles on specific techniques and applications can be found in open literature. Thus, here some basic adaptive beamforming concepts and criteria are presented next.

The choice of the weight vector 'w' is based on the statistics of the signal vector $x(t)$ received at the array. . Basically, the objective is to optimize the beamformer response with respect to a prescribed criterion. So that the output $y(t)$ contains minimal contribution from noise and interference. There are a number of criteria for choosing the optimum weights such as Minimum Mean Square Error (MMSE), Maximum Signal-to-interference Ratio (MSIR) and Minimum Variance (MV). In MMSE method, the error between the beamformer output $w^H x(t)$ and the desired signal $d(t)$ is minimized. The characteristics of the desired signal correlates with it to a certain extent and this is called a reference signal. The weights are chosen to minimize the MSE between the beamformer output and the reference signal and the weights come out to be $w_{opt} = R^{-1} r$ where $r = E\{x(t)x^H(t)\}$ and $r = E\{d(t)x(t)\}$. Here w_{opt} is referred to as optimum wiener solution. In MSIR method, the weights can be chosen to directly maximize the signal-to-interference ratio (SIR). This criterion also leads to the same optimum wiener solution for the weights. If the desired signal and its direction are both unknown, the way to ensure a good signal reception is to minimize the output noise variance. To ensure that the desired signal is passed with a specific gain and phase, a constraint may be used so that the response of the beamformer is $w^H v = g$. If $g = 1$ the response of the beamformer is often termed as minimum variance distortion less response (MVDR) beamformer. The solution for the optimal weights in all three cases is the same.

All these beamforming techniques are used to null the interferers as many as possible, which is limited due to the limited number of antenna elements in the antenna array. In the past, several methods of controlling the positions of the nulls have been employed, including element position perturbation, element phase only etc. Methods of producing such a null trough include, imposing multiple pattern nulls, imposing derivative constraints at the desired direction, and constraining the average power over an angular region. A null in an antenna pattern denotes a zero response. Instead of steering the beams towards all mobiles, one may shape the antenna in such way that it cancel interfering mobiles and produce a strong beam towards the wanted signal. This is done by placing the nulls in the pattern in the corresponding known directions of these interferers and simultaneously steering the main beam in the desired signal. This method of beam forming is known as null beamforming [12]. Adaptive arrays often referred as Smart antennas are proved to be useful to cancel directional interfering signals, improving the performance of cellular wireless communication systems [14]. An adaptive array with optimum weight vector can be used for null beamforming. The flexibility of array weighting to get he desired array pattern can be exploited to cancel directional sources operating even at the same frequency as that of the desired source, provided are not in the same direction of the desired source. In adaptive antenna theory the basic concept of nulling is based on number of antenna elements. An array with N number of antenna elements can null out N-1 interferers only. If the number of interferes are more than N-1 than the array become overloaded and performance starts degrading.

1.5 Thesis Organization

In chapter 2, a technique that involves the control of both the amplitude and phase, of every element in the array, by variation of a set of phase shifters is introduced. The technique may be used to resolve up to (n- 1) point sources of signal (or targets) without any limit on their angular separation.

In chapter 3, a beamforming algorithm is analyzed for flexible sidelobe adjustment. This algorithm is used to synthesize the Chebyshev pattern for equal sidelobe levels with a very fast convergence rate. This method is also used for null control in linear arrays. This is finally used to increase the capacity of a CDMA system by reducing the interference level of large number of interferers present in the system by presenting low sidelobe and forming nulls to all the undesired users.

In chapter 4, effect of proposed algorithm on CIR is simulated. There is reduction in interference power by proposed algorithm presenting low sidelobe levels to the undesired users leads to direct and increase in Carrier to Interference ratio (CIR).

Chapter 5 enlists the conclusion and the future scope of the present work.

Chapter 2

Independent Angular Steering of Each Zero of the Directional Pattern for a Linear Array

In this chapter, a technique that involves the control of both the amplitude and phase, of every element in the array (n-element linear array may possess up to (n- 1) independent zeros), by variation of a set of phase shifters is introduced. The technique may be used to resolve up to (n- 1) point sources of signal (or targets) without any limit on their angular separation.

2.1 Introduction

In this chapter, the directional pattern of an n-element linear array, that possess up to *(n-* 1) independent zeros is discussed. A method for independent control of the angular location of these zeros is also discussed. Although this process involves the control of both the amplitude and phase of every element in the array, the result may be achieved by variation of a set of phase shifters. The technique may in principle be used to resolve up to *(n-* 1) point sources of signal (or targets) without any limit on their angular separation [15]. The technique does not involve either superdirectivity or nonlinear signal processing.

2.2 Polynomial Representation of Linear Arrays

When the directional pattern of an n-element array is expressed in the polynomial form described by Schelkunoff, the resulting polynomial is of order $(n-1)$ and is given by:

$$D(\theta) = a_1 + a_2 Z + ------- a_n Z^{n-1} \tag{2.1}$$

Where

$$Z = \exp\left[j\frac{2\pi d}{\lambda}\sin\theta \right] \tag{2.2}$$

d is the inter element spacing and θ the direction relative to the array normal. Each coefficient of the polynomial represents the amplitude A_r, and phase α_r of each array element.

$$a_r = A_r \exp j\alpha_r \tag{2.3}$$

Such a polynomial may be represented as the product of $(n-1)$ factors giving the $(n-1)$ zeros of the directional pattern.

$$D(\theta) = (Z-b_1)(Z-b_2)(Z-b_3)------(Z-b_{n-1}) \tag{2.4}$$

Zeros of the polynomial represents real zeros of the directional pattern when they lie on the unit circle in the z plane. This leads to the result that there can be no more than $(n-1)$ independent zeros in the pattern of such an array.

A change in the angular location of any such zero corresponds to a change in the value of the corresponding factor of the array polynomial. Clearly such a change could alter the magnitude of each coefficient of the polynomial and hence could require a change in the amplitude and phase of each array element.

2.3 An Array of Arrays

Figure 2.1 shows 6-element linear array together with the phase shifting required to produce independent control of each zero in the directional pattern [16]. The output of each element is split into two, and the outputs combined in adjacent pairs via identical phase shifts ϕ_1. The directional pattern of each such element pair will be that of a 2-element array and given by:

$$D_1(\theta) = \cos\left[\left(\frac{d\pi}{\lambda}\sin(\theta)\right) - \frac{1}{2}\phi_1\right] \tag{2.5}$$

Since each such element groupings may be regarded as the elements of a 5-element array, each element having a directional pattern $D_1(\theta)$ we may now apply the same procedure as before; except that the groupings now employ a phase shift ϕ_2.

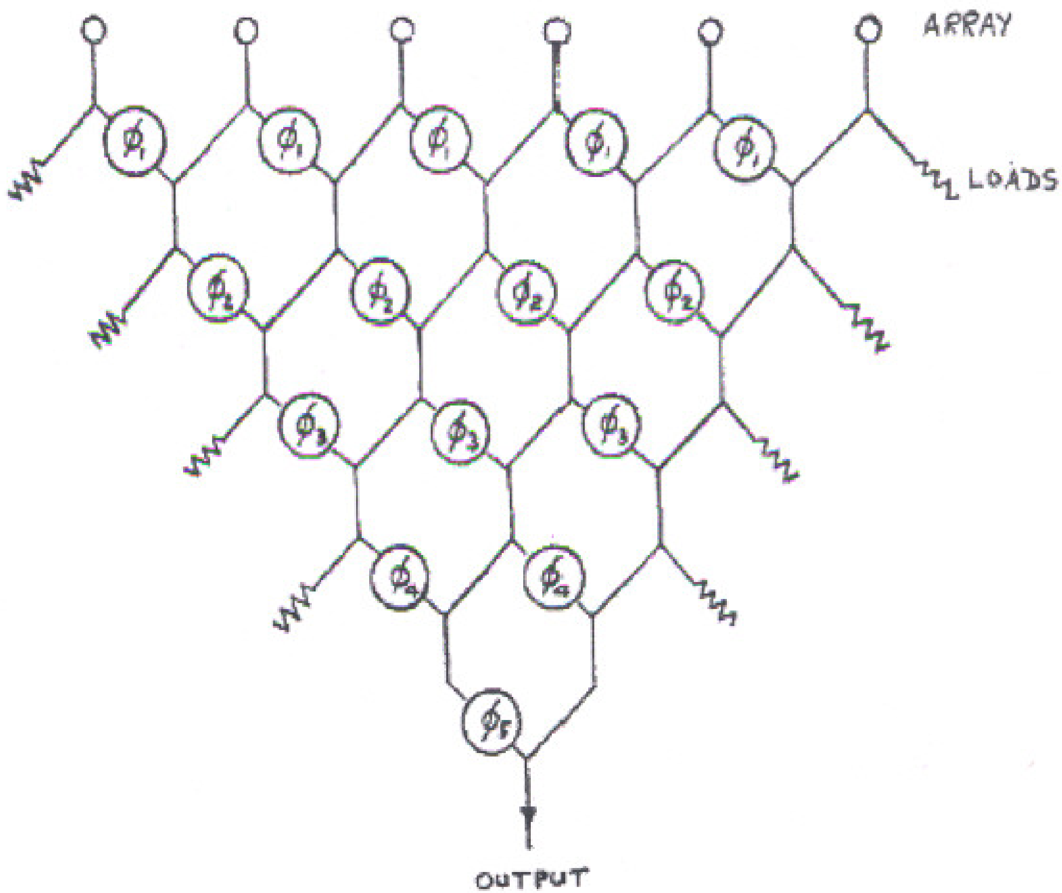


Figure 2.1. Schematic diagram of arrangement for producing independent angular location of the 5 zeros of a 6-element linear array. The power division and combination could most easily be performed in hybrid tee circuits.

The directional pattern of each of the 4 outputs from the new groupings may be deduced from the product theorem as the product of the array combination $D_2(\theta)$ and the effective element pattern $D_1(\theta)$.

$$D_1(\theta)D_2(\theta) = \cos\left[\left(\frac{d\pi}{\lambda}\sin(\theta)\right) - \frac{1}{2}\phi_1\right]\cos\left[\left(\frac{d\pi}{\lambda}\sin(\theta)\right) - \frac{1}{2}\phi_2\right] \tag{2.6}$$

Clearly the overall pattern for an n-element array with such a phasing system will be:

$$D(\theta) = \prod_{r=1}^{r=(n-1)} \cos\left[\left(\frac{d\pi}{\lambda}\sin(\theta)\right) - \frac{1}{2}\phi_r\right] \tag{2.7}$$

The overall directional pattern is thus the product of *(n* - 1) terms, each representing the pattern of a 2-element array, and if $d = \lambda/2$, each such virtual couplet possesses one zero in the range of real angles. Evidently the zero associated with $D_1(\theta)$ may be positioned in space merely by the choice of the phase shifts, which must all be identical. Each zero of the pattern may therefore be positioned by suitable choice of the value of the set of phase shifters associated with that zero. Equation (2.7) also represents a way of expressing the pattern of a linear array in terms of the product of *(n*- 1) sine wave components.

The differing combinations of phase shift will cause the appropriate values of amplitude and phase to be set up across the array, but it is significant to notice that there is no restriction on the angular spacing between the zero, and closely spaced zeros do not represent superdirective directional patterns. The technique may of course be extended to apply to superdirective combinations by considering inter-element spacing less than λ/2, but there is probably little practical significance in such an application. It is also significant that the product of the co sinusoidal components of the overall directional pattern is not due to nonlinear signal processing. The process is therefore linear, and superposition applies for multiple target excitation.

The previous analysis has assumed vector addition of the signals at each summing (or power dividing) point in Figure 2.1. In practice, this can be achieved most simply by combining the signals in a hybrid tee or hybrid ring circuit, which provides a sum and difference output.

There are numerous possible applications for the technique described above. One obvious application is the provision of one or two steerable zeros in the directional pattern of receiving arrays for HF communications. Such zeros could be used to reject unwanted interfering signals. The restrictions of wide bandwidths and limited array dimensions often preclude the design of low-side lobe directional patterns in the HF band and, in such instances, the steerable zeros could result in a considerable improvement in signal-to-medium noise ratio.

There is of course no need to employ all the $(n-1)$ available zeros and thus to simplify the arrangement of Figure 2.1. The ultimate theoretical limit of the proposed system is the ability to receive, independently, signals from n separate directions and with zero cross talk; though this limit neglects the effect of the finite receiver bandwidth on the directional pattern. There is, however, no finite lower limit on the angular separation of these signals, and the technique is therefore able to resolve up to n signal sources or targets even within the conventional beamwidth of the array.

2.4 Sum and Difference Outputs

If such a phasing system is to be used to receive separate signals arriving from different directions, it is necessary to provide several different outputs from the directional receiver, such that in each case a different zero is absent from the directional pattern. For the case of each interferometer pattern, the removal of the zero can best be effected by the introduction of a π phase shift, which will move the cosine wave component of the directional pattern from a zero to a peak in the direction concerned. This result is automatically achieved if the signals from each element pair are added in a hybrid ring. This approach is shown in Figure 2.2 for a 4-element array. The S output (sum output) of each hybrid will be defined as the output giving the maximum response for the direction associated with each set of phase shifts. The D output (difference output) will therefore represent the location of the zero.

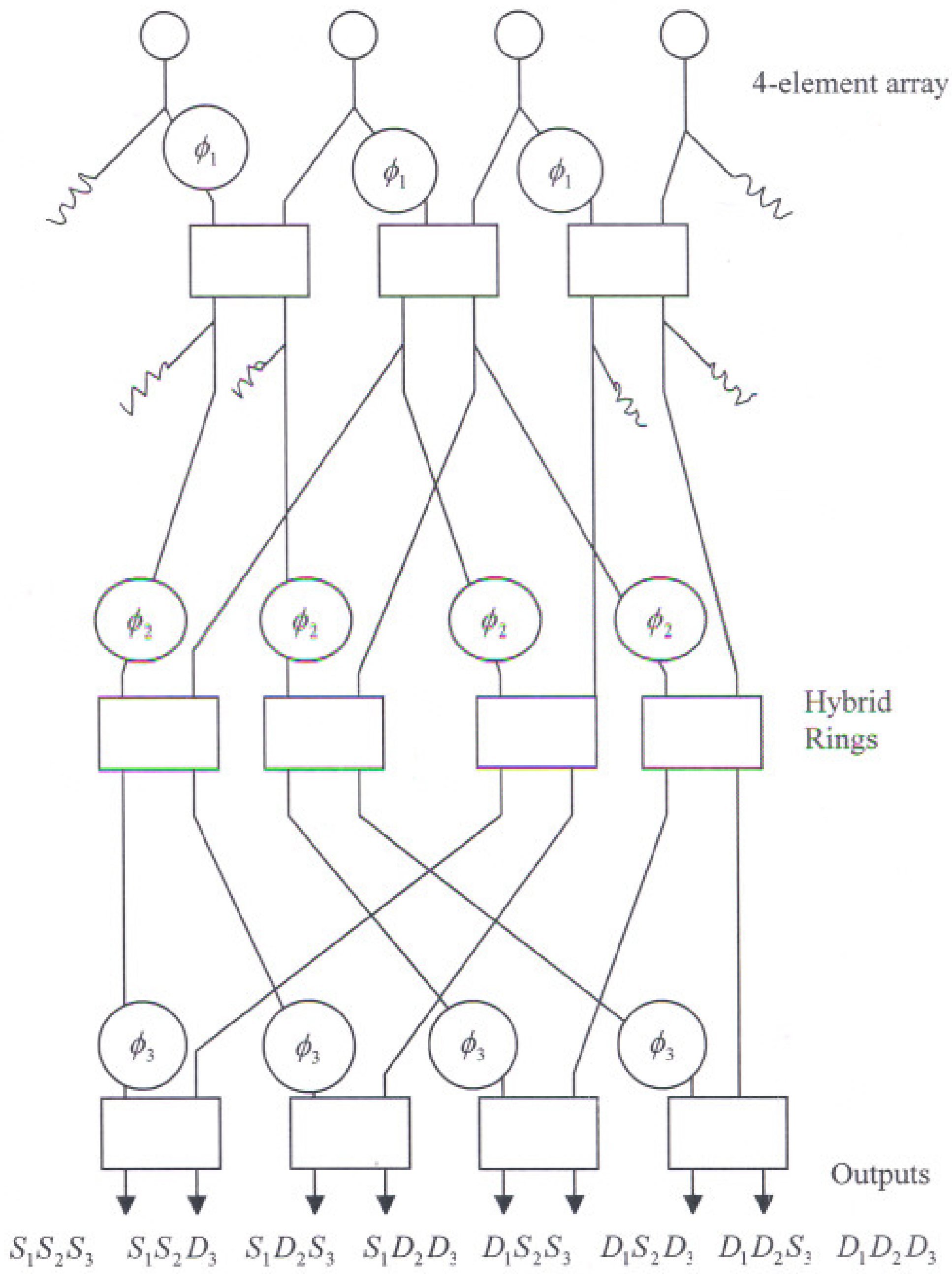


Figure. 2.2. Schematic arrangement for producing the 8 possible sum and difference outputs in the directions corresponding to the 3 directional zeros of a 4-element array.

The arrangement in Figure 2.2 shows 8 different outputs, each denoted by three symbols such as $S_1D_2S_2$ which means that this particular output corresponds to a sum output for the direction $\theta = \sin^{-1}((\lambda / 2nd)\phi_1)$, a zero in the direction

$\theta = \sin^{-1}((\lambda / 2nd)\phi_2)$ and a sum output in the direction $\theta = \sin^{-1}((\lambda / 2nd)\phi_3)$. For an n-element array: the maximum number of such output combinations is given by 2^{n-1}, but for the purpose of the independent reception of $(n-1)$ signals, only $(n-1)$ outputs are required. Therefore, in the case of the 4-element array of Figure 2.2 the only outputs required would be the $S_1D_2D_3$, the $D_1S_2D_3$, and the $D_1D_2S_3$ outputs. This results in a simplification of the arrangement of hybrids shown in the diagram.

It can be seen from both Figures 2.1 and 2.2 that there is a small loss of received energy owing to the necessity of terminating certain output arms in loads. This amounts to less than 20 percent of incident power for the arrangement of Figure 2.1.The technique results in the formation of $(n-1)$ independent directional patterns. However, the patterns need not be similar in shape, nor need they possess the same directional gain in the directions corresponding to the signal sources. This is because there is no reason to suppose that the maximum of the directional pattern so formed corresponds to the direction of reception. Thus if all the sources (and consequently all the zeros of the array) are uniformly distributed along the $\sin\theta$ scale; the resulting set of direction patterns would correspond to an orthogonal set of $\sin nx / n \sin x$ functions.

If on the other hand the sources are close together, the patterns corresponding to outputs from each source will receive the required signal on what might normally be described as a side lobe of the directional pattern. We can therefore refer to a sensitivity of each output of the directional receiver in the direction of the signal source. This will not necessarily be the same as the gain of the pattern, which by convention is defined relative to the maximum of the pattern.

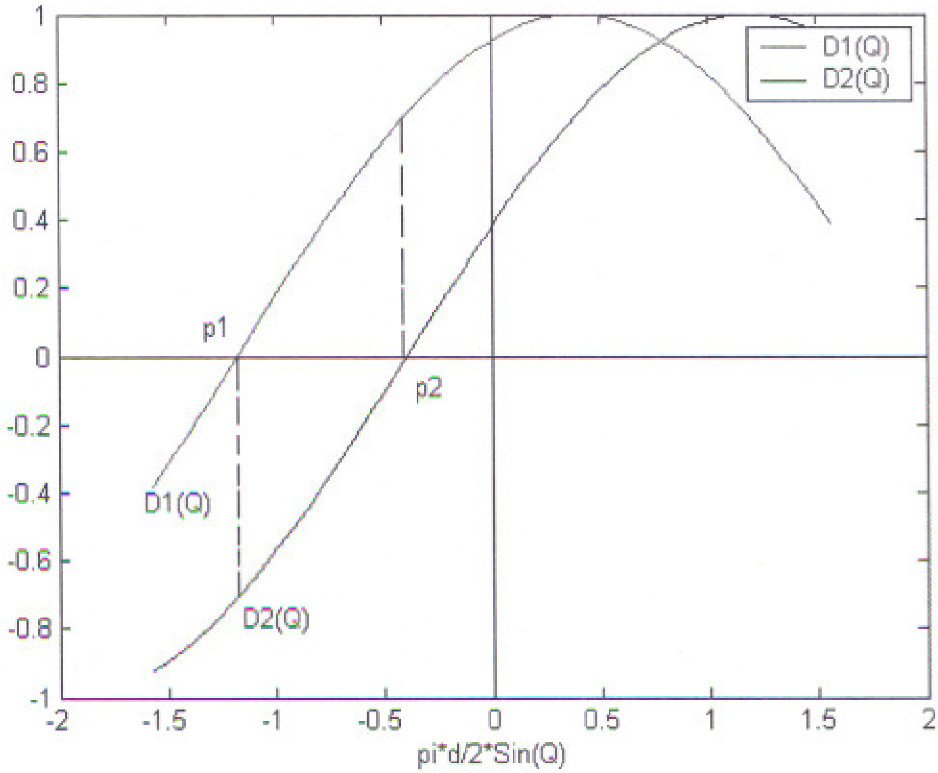


Figure 2.3. p_1 and p_2 represent the angular location of the 2 directional zeros of a 3-element array, and $D_1(\theta)$ represents two sinusoidal components of the directional pattern. The magnitude of $D_1(\theta)$ at p_2 and of $D_2(\theta)$ at p_1 represent the relative sensitivity of these two patterns of signals at these patterns to angles. It can be seen that, as p_1 and p_2 becomes closer together, these sensitivities decreases.

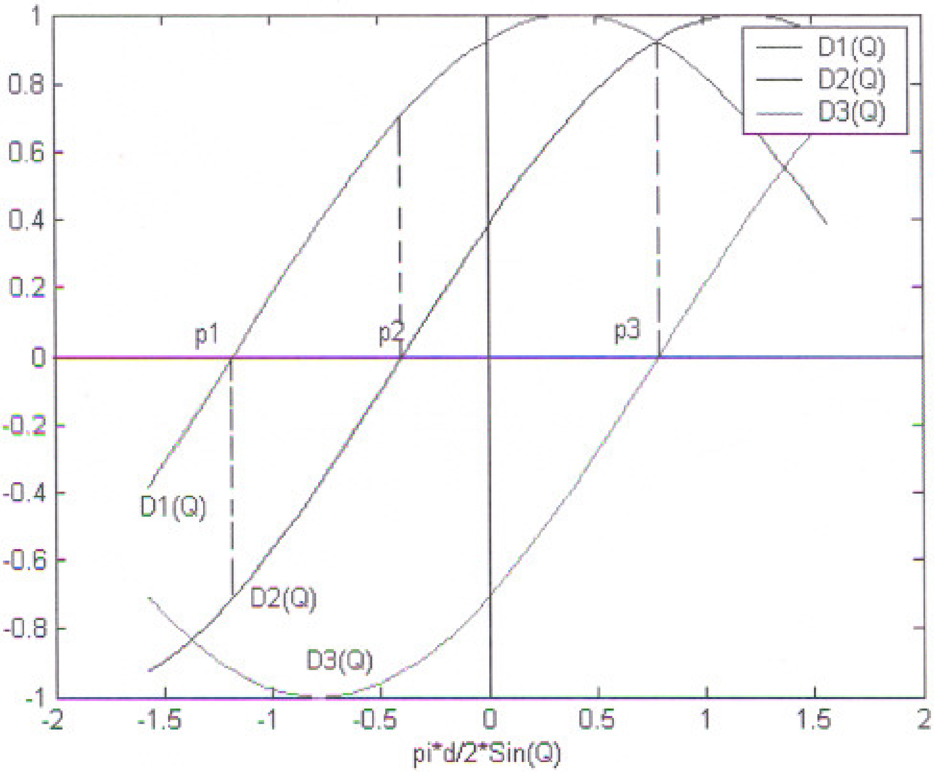


Figure 2.4. p_1, p_2& $p3$ represent the angular location of the 3 directional zeros of a 4-element array, and $D_1(\theta)$ represents two sinusoidal components of the directional pattern. The magnitude of $D_1(\theta)$ at p_2 and of $D_2(\theta)$ at p_1 and of $D_3(\theta)$ at p_1 & p_2 represent the relative sensitivity of these patterns of signals at these patterns to angles. It can be seen that, as p_1, p_2& p_3 becomes closer together, these sensitivities decreases.

The significance of the directional sensitivity of each output may easily be seen by reference to Figure 2.3 and Figure 2.4, which shows the two constituent patterns of a 3-element array given by S_1D_1 and S_2D_2 and three constituent patterns of a 4-element array respectively. These are plotted on a *p* scale where $p = rd/\lambda \sin(\theta)$, and each consists of a cosine wave. If two targets or sources are the same as the gain of the pattern, which by convention is defined relative to the maximum of the pattern located in directions *pl* and *p2* as shown, it can be seen that although in principle the two outputs provide the signals from each source without any interference between them, as the sources become closer together the sensitivity of each output decreases, reaching zero for the case of zero separation. In this simple case, the variation of sensitivity with separation between zeros is sinusoidal but, in the more general case, it depends upon the location of every other zero.

The obvious result of the loss of sensitivity is a loss of S/N ratio in a practical system and this leads to the conclusion that it is possible to exchange S/N ratio for the ability to resolve closely spaced targets, provided that the total number of targets does not exceed $(n-1)$.

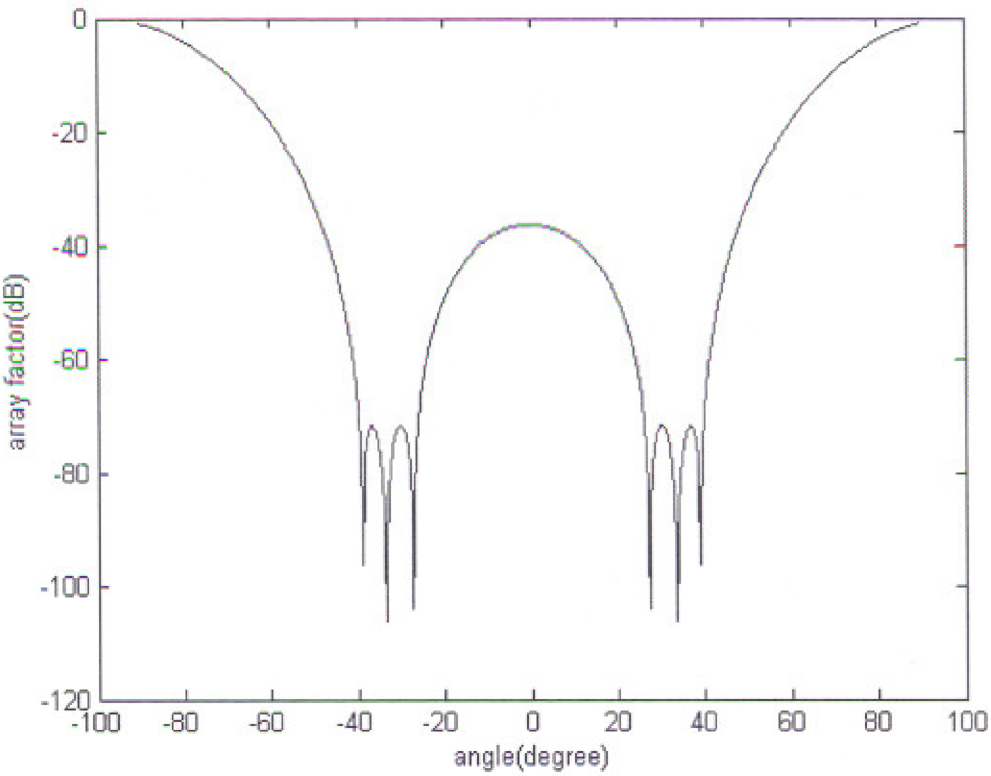


Figure 2.5:Plot showing zeros at phase shifts (ϕ_r) $20^0, 30^0, 40^0$ for 4-element linear array

i.e. phase difference of 10^0

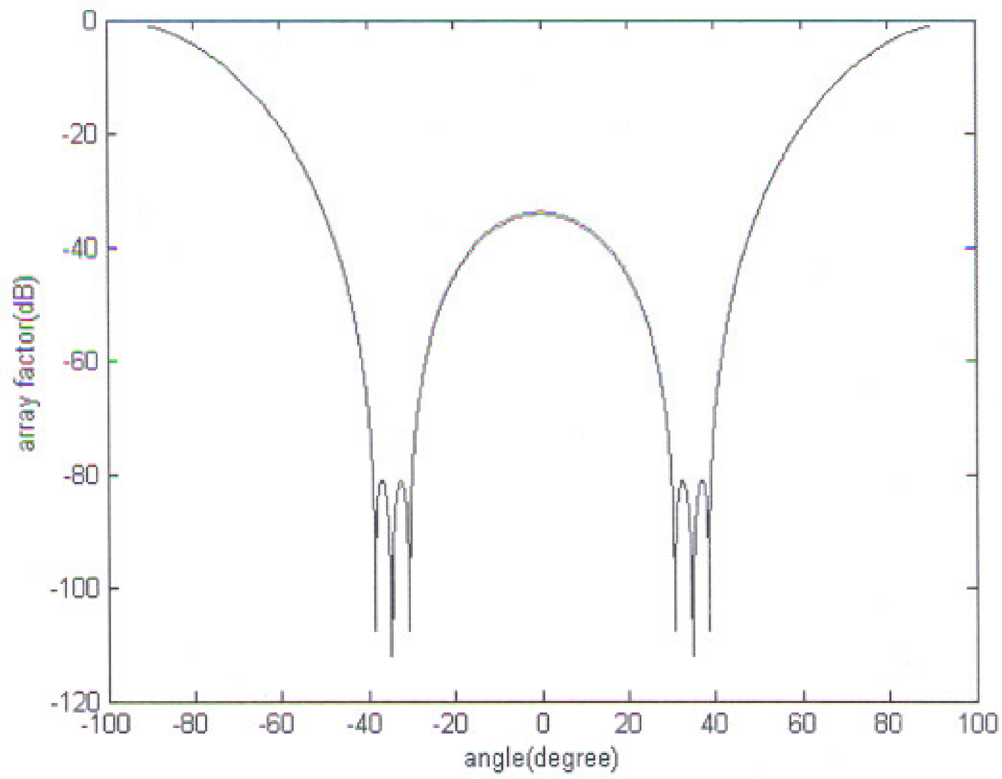


Figure 2.6:Plot showing zeros at phase shifts (ϕ_r) $25^0, 32^0, 39^0$ for 4-element linear array

i.e. phase difference of 7^0

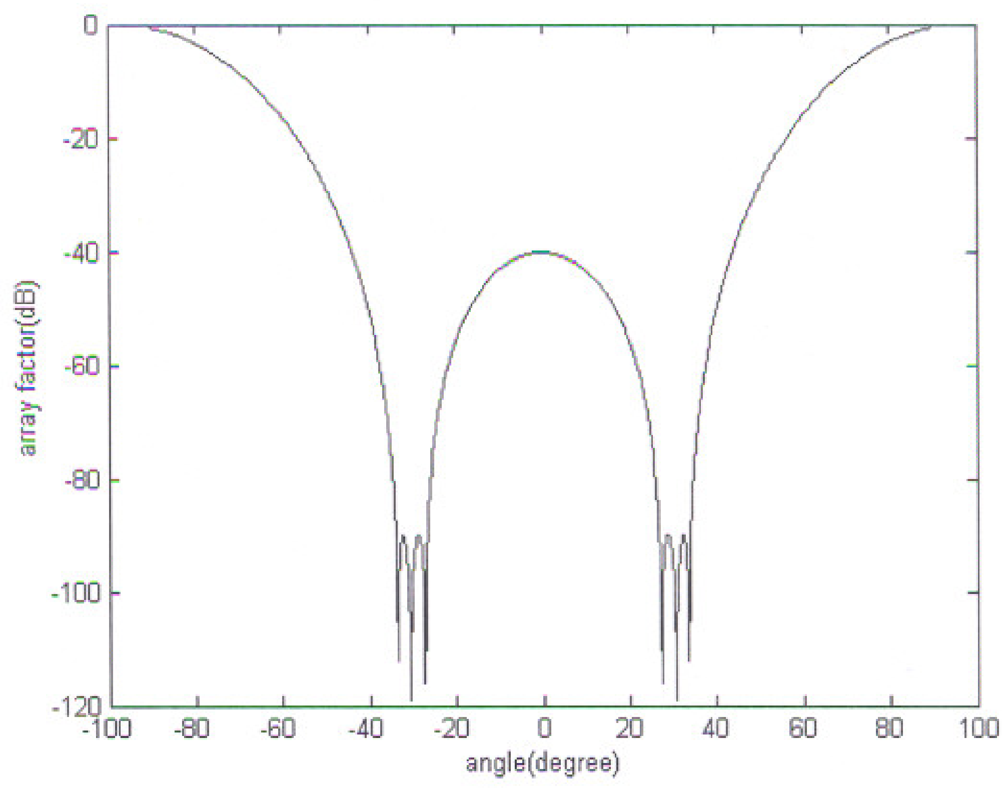


Figure 2.7:Plot showing zeros at phase shifts (ϕ_r) $25^0, 30^0, 35^0$ for 4-element linear array

i.e. phase difference of 5^0

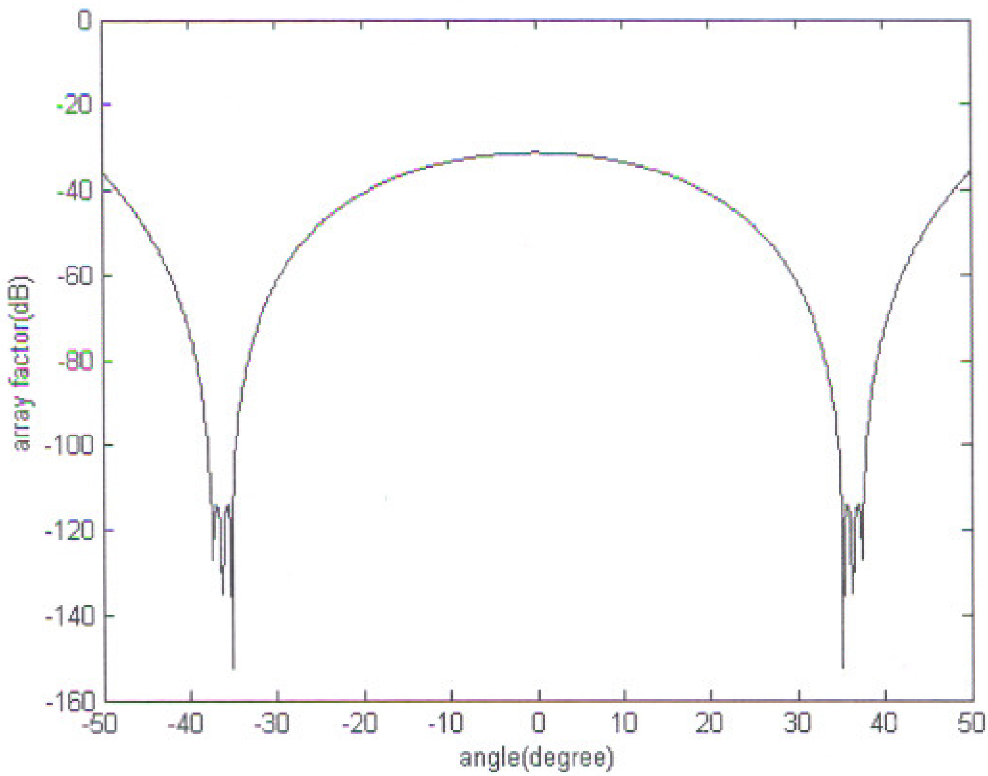


Figure 2.8:Plot showing zeros at phase shifts (ϕ_r) $33^0, 35^0, 37^0$ for 4-element linear array i.e. phase difference of 2^0.

(Expanded view to show zeros clearly from –50 to 50)

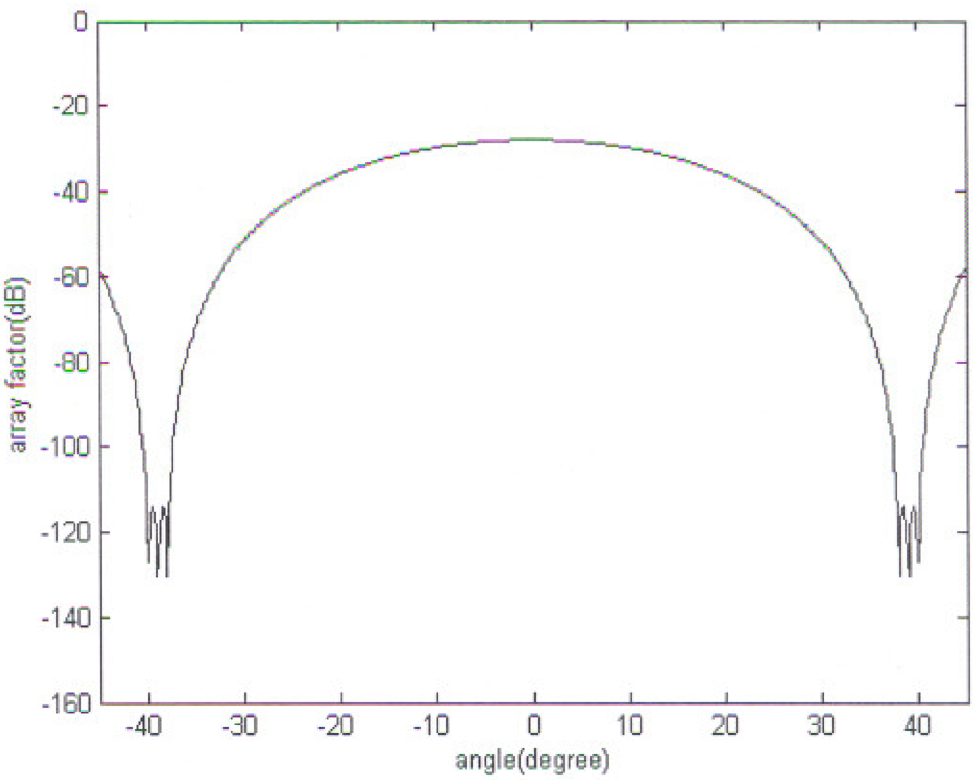


Figure 2.9:Plot showing zeros at phase shifts (ϕ_r) $38^0, 40^0, 42^0$ for 4-element linear array i.e. phase difference of 2^0. (Expanded view to show zeros clearly)

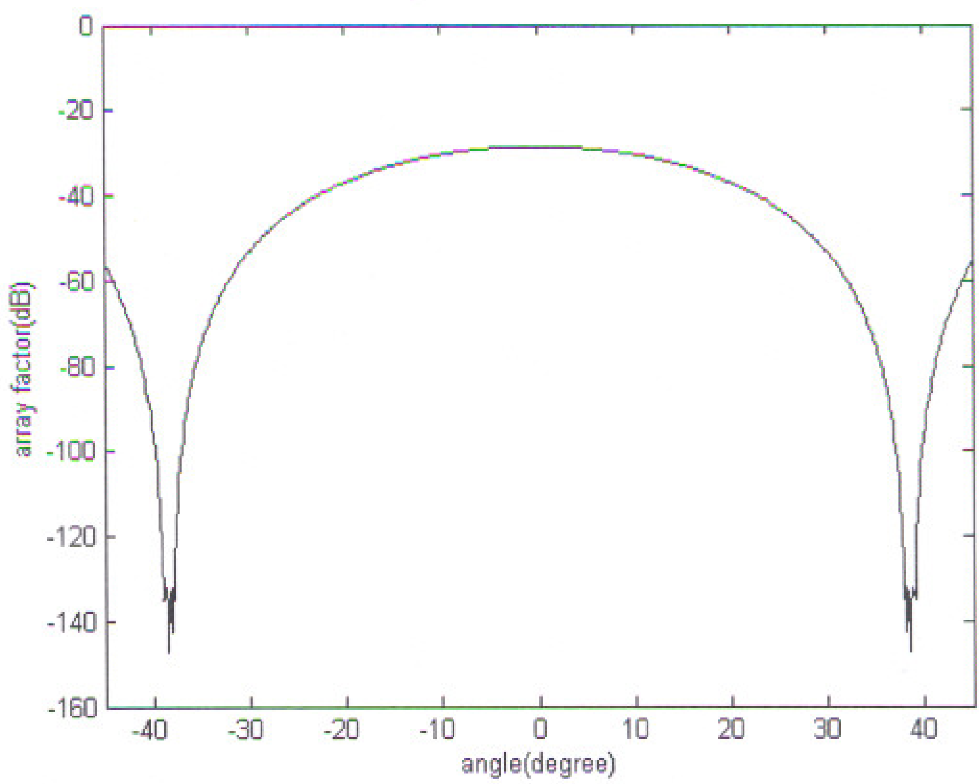


Figure 2.10:Plot showing zeros at phase shifts (ϕ_r) $38^0, 39^0, 40^0$ for 4-element linear array i.e. phase difference of 1^0. (Expanded view to show zeros clearly).

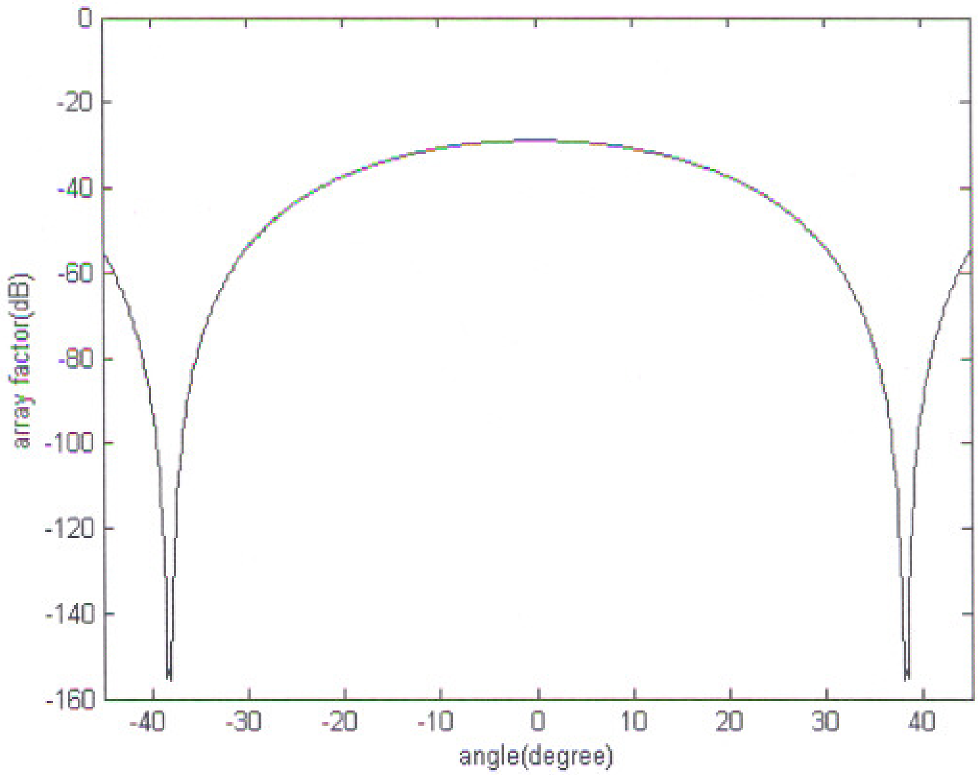


Figure 2.11:Plot showing zeros at phase shifts (ϕ_r) $38^0, 38.5^0, 39^0$ for 4-element linear array i.e. phase difference of 0.5^0. (Expanded view to show zeros clearly)

Using equation (2.7), minimum difference between the phase shifts has been calculated to produce independent control of each zero in the directional pattern. This is computed by varying differences in phase shifts in a linear array. Here for 4-element array is considered. Initially a phase difference of 10^0 i.e. at $(20^0, 30^0, 40^0)$ is taken between elements of a liner array as shown in Figure 2.5. Then phase difference is reduced between the elements and a phase difference of 7^0 i.e. at $(25^0, 32^0, 39^0)$ is taken as shown in Figure 2.6, a phase difference of 5^0 i.e. at $(25^0, 30^0, 35^0)$ as shown in Figure 2.7, a phase difference of 3^0 i.e. at $(33^0, 35^0, 37^0)$ shown in Figure 2.8, a phase difference of $2^0 (38^0, 40^0, 42^0)$ shown in Figure 2.9, a phase difference of $1^0 (38^0, 39^0, 40^0)$ shown in Figure 2.10 and then a phase difference of $0.5^0 (38^0, 38.5^0, 39^0)$ is taken as shown in Figure 2.11. It can be seen from theses figures that a minimum phase difference of 1^0 can be taken to produce independent control of zero in directional pattern. If phase difference is less than 1^0, than zeros cannot be controlled in directional pattern as shown in Figure 2.11 where a phase difference of 0.5^0 is taken.

Chapter 3

A Technique for Creating Equal Side Lobes and Null Formation in Antenna Arrays

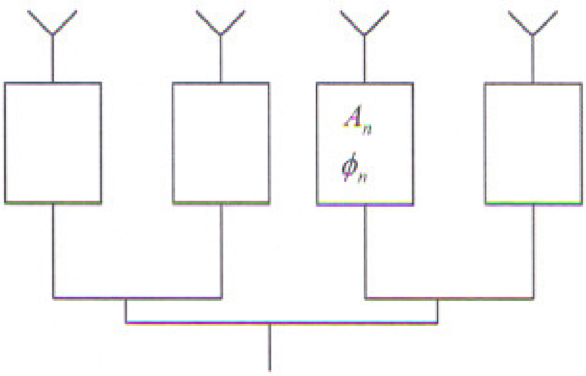
In this chapter, a beam-forming algorithm is described for flexible side lobe adjustment and null formation in antenna arrays. In the mobile communication systems like CDMA where the intra cell interferers are large in number, side lobe adjustment would be a simple solution towards suppressing co-channel interference. The algorithm places a very low side lobe level over a large width in the beam pattern. In this algorithm mean square error is user define, so this is very flexible. The convergence of this algorithm is fast and requires only two to three iterations. . This method is based on full amplitude / phase control at each array element. These features are largely independent of any algorithm for achieving the nulls, and therefore they also provide a perspective on the performance of the adaptive antenna systems. The algorithm provides flexible parameter adjustment (side lobe level, null depth, main lobe width and null width) together with very low computational effort.

3.1 Introduction

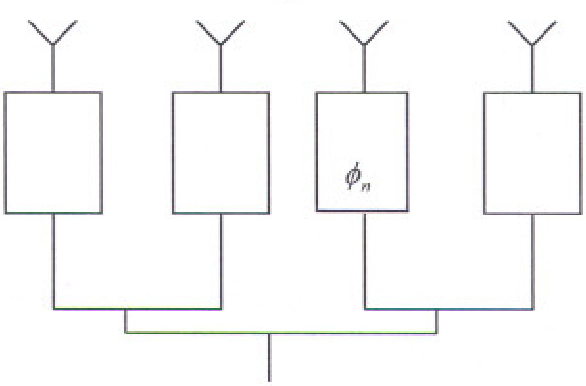
Antenna arrays reduce the co-channel interference by spatial variations of antenna gain [17]. This improves the QoS and hence the system capacity by a large margin as compared to omni-antenna at the BS of mobile communication systems. In CDMA systems as the number of co-channel interferers is very large, antenna array is going to be an integral part of the 3G systems. Owing to large number of interferers, to know the angular directions of all the interferers for a MS would be a cumbersome task, if not impossible to form the beam to null them. In the uplink, covariance matrix is estimated to find out the DOAs (direction of arrivals) of the interferers of a mobile station (MS) and maximize the signal to interference ratio for its proper beam forming. In CDMA mobile communication systems the main criterion for beam forming is to maximize the power received from the desired direction and minimizing the average power in the undesired direction. It should be noted that a receiver with M antennas could suppress M-1 interfering signals. Thus, either by nulling the error prone non-unique directions of the interferers or by using an adaptive side lobe adjustment would be better. This would require a beam forming algorithm capable of shaping the overall side lobe levels or nulling/reducing the gain in the individual interferers direction. It should be capable of providing different side lobe level requirements with one algorithm. The beam forming technique analyzed in this chapter is capable of obtaining a Chebyshev pattern with minimum equal side lobe level for a given main lobe beam-width and vice versa.

The method to provide control of the nulls of the antenna pattern, are of interest for two different, but related reasons. First, they represent generalizations of classical pattern synthesis techniques, which deal with the main beam shape and the sidelobe envelope, but neglect the detailed sidelobe structure. Due to the increasing pollution of the electromagnetic environment, synthesis methods, which allow placing one or more nulls in the pattern at specified directions, are becoming important. The second reason is that they provide insight into adaptive antenna systems [18]. Discussion of these systems generally emphasizes the choice, implementation and performance of an adaptive algorithm. Equally important however, are such fundamental questions as: what is the optimal control architecture for the system, what is the minimum number of degrees of freedom required, how severe is the pattern deterioration, what is the attainable null depth and what are the ultimate limitations? These questions, which are independent of any particular algorithm, can be addressed by focusing attention on direct pattern null synthesis, since the final state of any adapted system is a pattern with nulls in the directions of the jammers. In this approach one can readily investigate the characteristics of such null-constrained patterns, when synthesized with various forms of control of the array excitation.

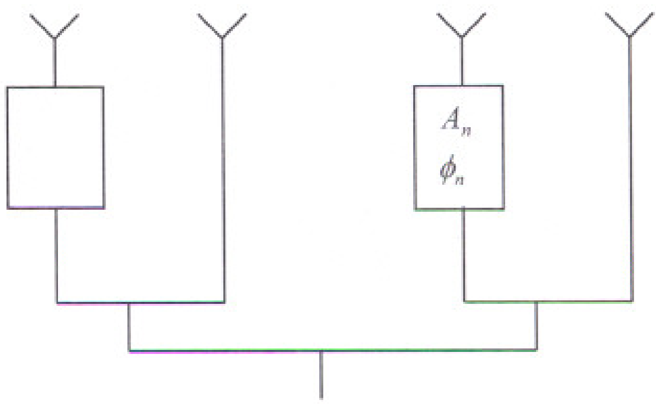
Pattern control in an array antenna can be achieved in various ways. Some common configurations are shown in Figure 4.1. The most general but also most costly alternative clearly is control of both amplitude and phase of each array element. A second alternative is through perturbation of element phase only, which is attractive since in a phased array the required controls are available at no extra cost. A third method is to incorporate controls only at a select subset of elements or at the subarray level, which is tempting because it reduces the number of electronic controls [19]-[23].



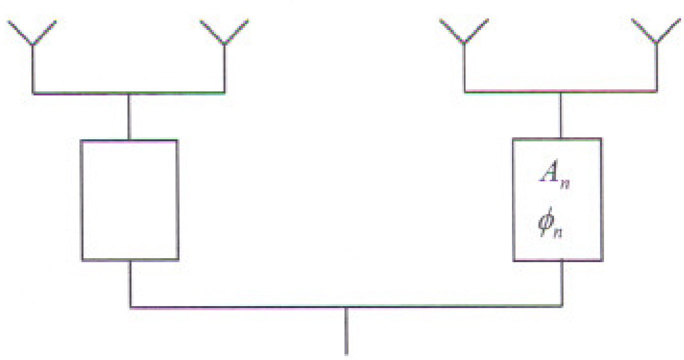
(a) Amplitude / Phase



(b) Phase Only



(c) Select Elements



(d) Subarray Weighting

Figure 3.1. Typical control configurations.

3.2 System Model

A linear array of $2N+1$ isotropic equispaced elements (ULA) is considered, which has the pattern

$$f(u) = \sum_{-N}^{N} a_n e^{jnkdu} \tag{3.1}$$

where a_n denote the element excitation, k the wave number i.e. $\frac{2\pi}{\lambda}$, d the inter-element spacing and u is the sine of the angle θ from broadside i.e. $u = \sin\theta$.

The method for pattern null synthesis starts from a given original pattern $f_0(u)$, with desired main beam and sidelobe envelope, corresponding to given original element coefficients $\{a_{0n}\}$. These coefficients are then perturbed such that the pattern has nulls at the desired directions. Figure 3.1 shows the pattern for $2N+1=41$, d=$\lambda/2$, $c_n=1$.

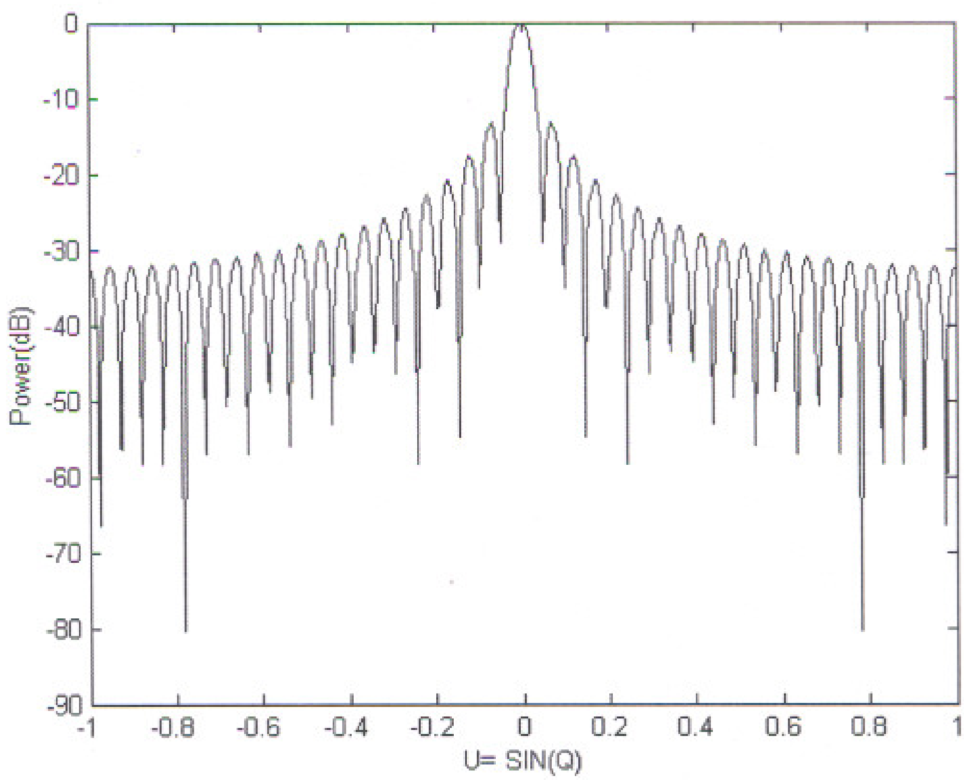


Figure 3.2. Pattern with nulls for $2N+1=41$, d=$\lambda/2$, $c_n=1$

For the case with full amplitude and phase control we define the desired pattern $f(u)$ mathematically by the criterion

$$f(u_m) = 0, \qquad m = 1,2, \ldots\ldots, M \tag{3.2}$$

$$\sum_n c_n |a_n - a_{0n}|^2 = \text{minimum} \tag{3.3}$$

Equation (3.2) ensures that the synthesized pattern has nulls at the desired directions u_m, and equation (3.3) ensures that the array excitation is only minimally perturbed. The real positive symmetric coefficients c_n add flexibility to the criterion.

The solution for the perturbed element coefficients is

$$a_n = a_{0n} - \sum_{m=1}^{M} \gamma_m (1/c_n) e^{-jnkdu_m} \tag{3.4}$$

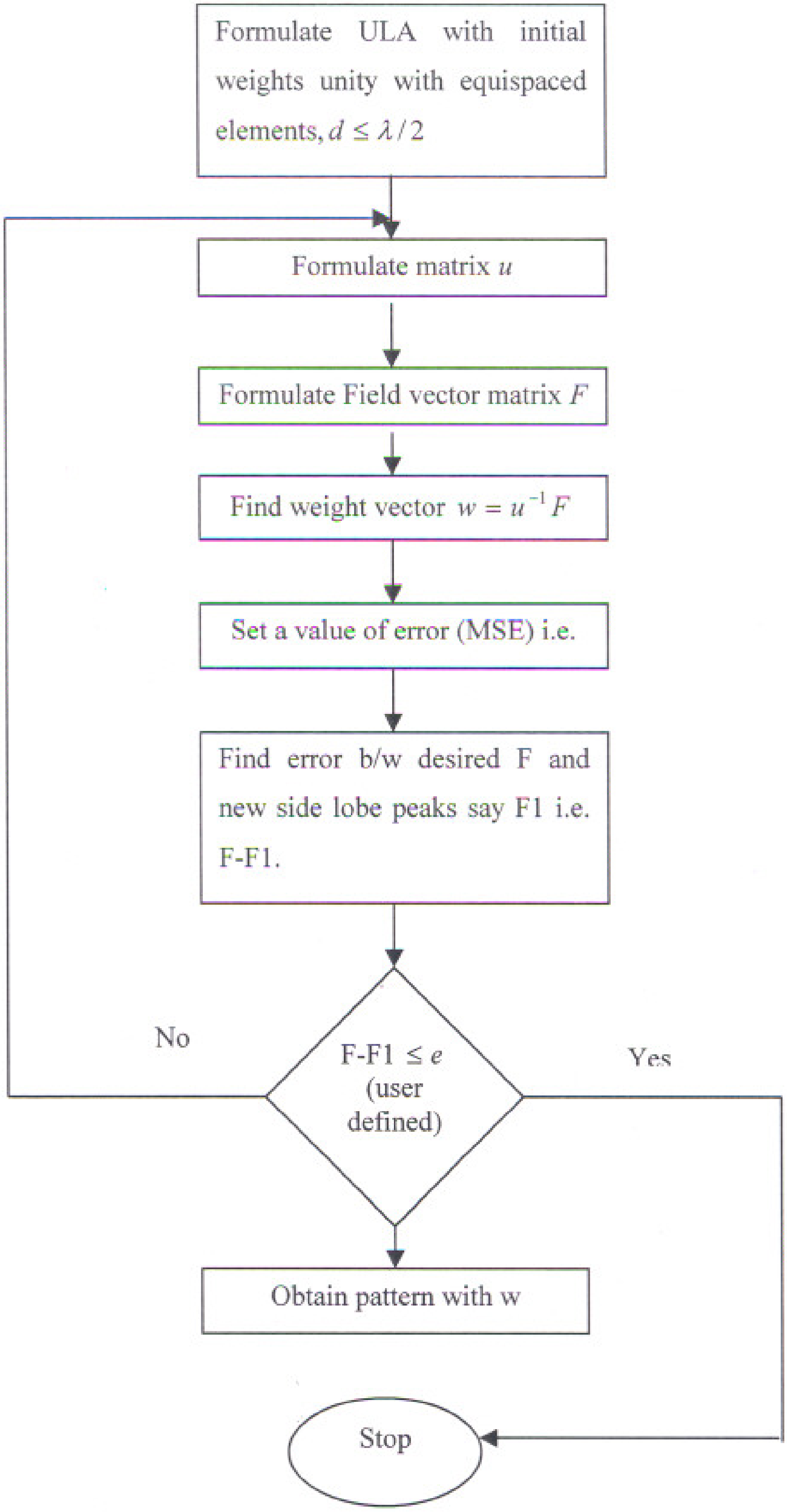
where the beam coefficients γ_m are determined from an M^{th} order system of linear equations. Hence the perturbed pattern is

$$f(u) = f_0(u) - \sum_{m=1}^{M} \gamma_m \sum_n (1/c_n) e^{jnkd(u-u_m)} \tag{3.5}$$

Note that in (3.5) each term in the sum over m represents one cancellation beam with amplitude coefficient γ_m and the direction u_m of the desired null. The null synthesis problem thus has only the dimensionality M, rather than the dimensionality $2N+1$ of element space. This represents a significant simplification of the problem. Thus, using real weights at the antenna elements the desired beam can be formed, i.e. the appropriate levels of the main lobe and side lobes can be obtained and by applying a proper phase shift to the antenna elements the beam can be steered. The position of nulls would be determined by the width of the sidelobes. Different applications require different beamforming constraints. Some may require proper positioning of nulls in particular directions like radars while some may require lower sidelobes relative to the main lobe like mobile communications. In CDMA mobile communications where there are large number of interferers, a beamforming technique is sought that would efficiently suppress the power in the undesired direction at the same time maximizing the power in the desired direction. As the antenna array could be of only finite size, it has finite degree of freedom, i.e., only N-1 nulls can be placed for an N element antenna array. But the number of co channel mobile stations are much larger than N. Moreover to place these nulls we must know the direction of the interferers, which introduces additional complexity. A beam forming technique that maximizes the power in the desired direction and minimizing the average power in the undesired direction is the main criterion required for beamforming. One more concern is that once a beam is formed for given sidelobe levels, it should remain constant while steering the beam by applying proper phase shift. These issues are resolved in this beamforming technique.

Our requirement is to form the antenna beam for given sidelobe levels in specific angular space. As the total power in the beam remains constant, the required sidelobe levels could be achieved by placing the nulls properly in the angular space. Chebyshev gave a polynomial function approach to determine such position of nulls, which would give equal sidelobe levels. This would be a nice approach if we were only concerned with equal sidelobe levels. In mobile communications, at the BS, the beam formation should be able to achieve any arbitrary sidelobe levels as per the requirements. Thus a generalized and flexible technique is required to achieve this.

3.3 Algorithm Used For Forming Equal Side Lobes



3.4 Results & Conclusion

Convergence:

The convergence of the proposed algorithm is proved, by synthesizing the Chebyshev antenna pattern, as it is the only and finest example of optimum beam forming with equal side lobe levels for a minimum beam width. This method is applied to uniform linear array for different number of elements and the beam pattern is finally converged to Chebyshev pattern. The uniform linear array pattern is known to have minimum beamwidth (BW), and the finally converged beam also has minimum beamwidth for a given sidelobe level, which is similar to the Chebyshev beam pattern. The comparison of BW is given in Table 3.1. For N=10, starting with initial BW=21.54 for first sidelobe at 13 dB, the converged beam has a BW=22.60 for equal side lobe level (ESLL) =30 dB.

Table 3.1: The initial and final beam width for different antenna elements

No. of elements	Initial Beamwidth (deg)	Converged Beamwidth (deg)
10	21.54	22.60
16	10.48	13.75

For number of elements, N=10, a power pattern of a broadside array is obtained with a constraint of equal side lobe levels equal to –30 dB. The initial and final patterns are shown in Figure 3.3(a) and Figure 3.4(c). To get Chebyshev antenna pattern for required beam, it took only three iterations. The convergence /error graph is shown in Figure 3.4(d) for ten numbers of antenna elements showing the algorithm to have a fast convergence. Similar observations were made with number of antenna elements N=16. The initial and final beam pattern is shown in Figures 3.5(a) and 3.6(b) respectively. The convergence is shown in Figure 3.6(c). The initial beampattern for ULA with 20 elements is shown in Figure 3.7(a). In Figure 3.8(b) the converged beampattern is shown. The convergence speed is shown in Figure 3.8(c).

1. (a) **No of elements in array** = 10,
Error =0.05,
No of iteration required=2,
Total time taken = 20.6seconds

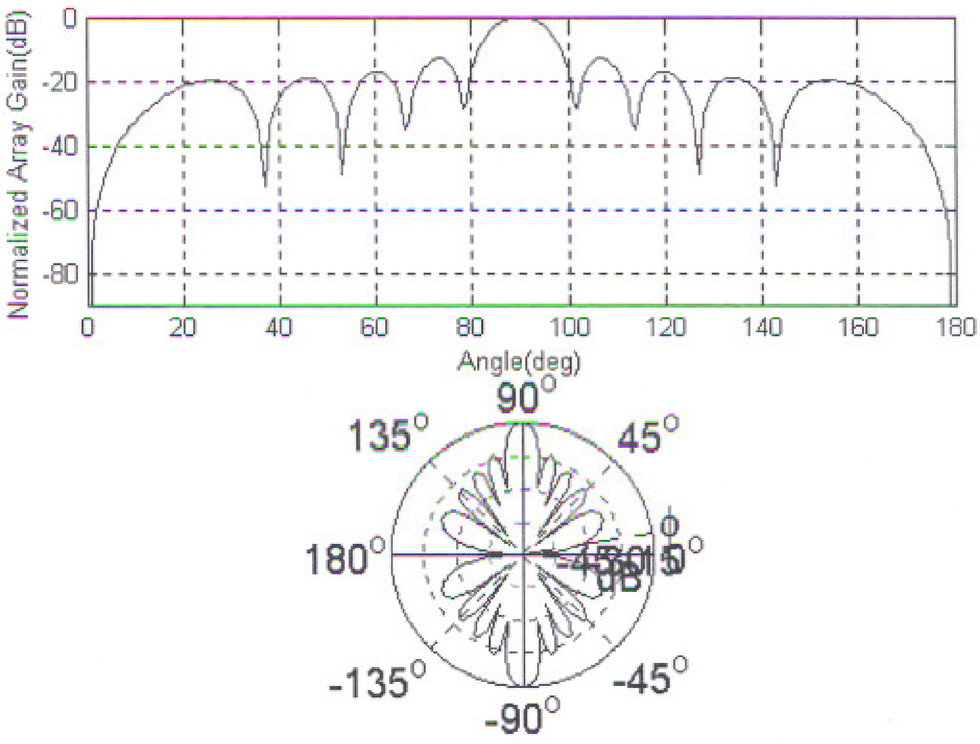


Figure 3.3(a): Pattern of linear array for N=10, d=λ/2

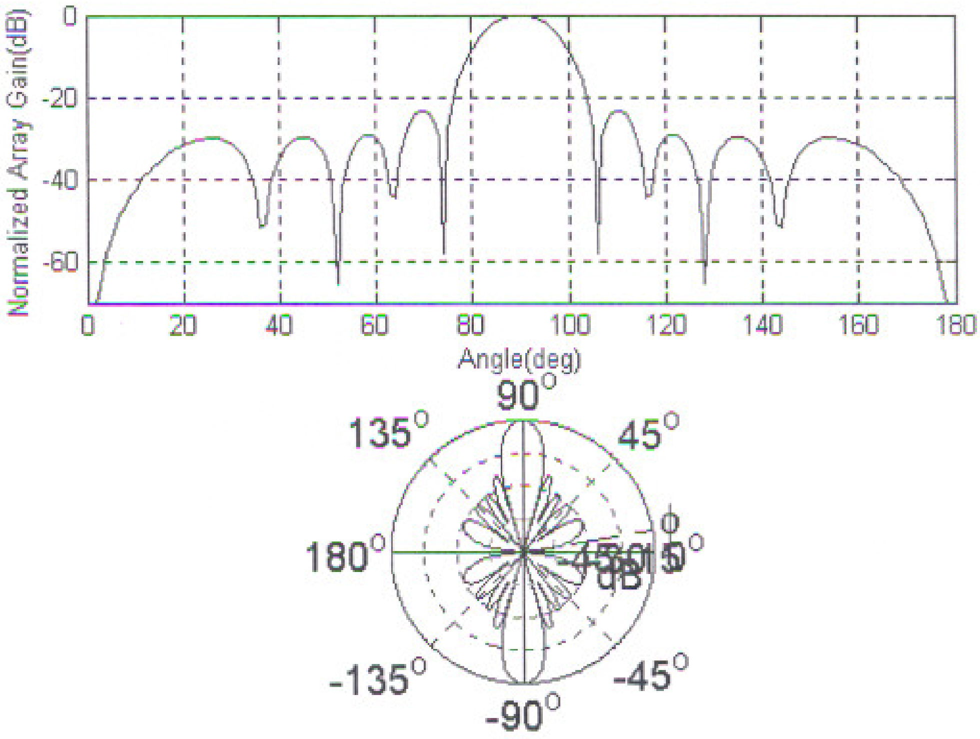


Figure 3.3(b): Pattern of linear array for N=10, d=λ/2 after 1st iteration.

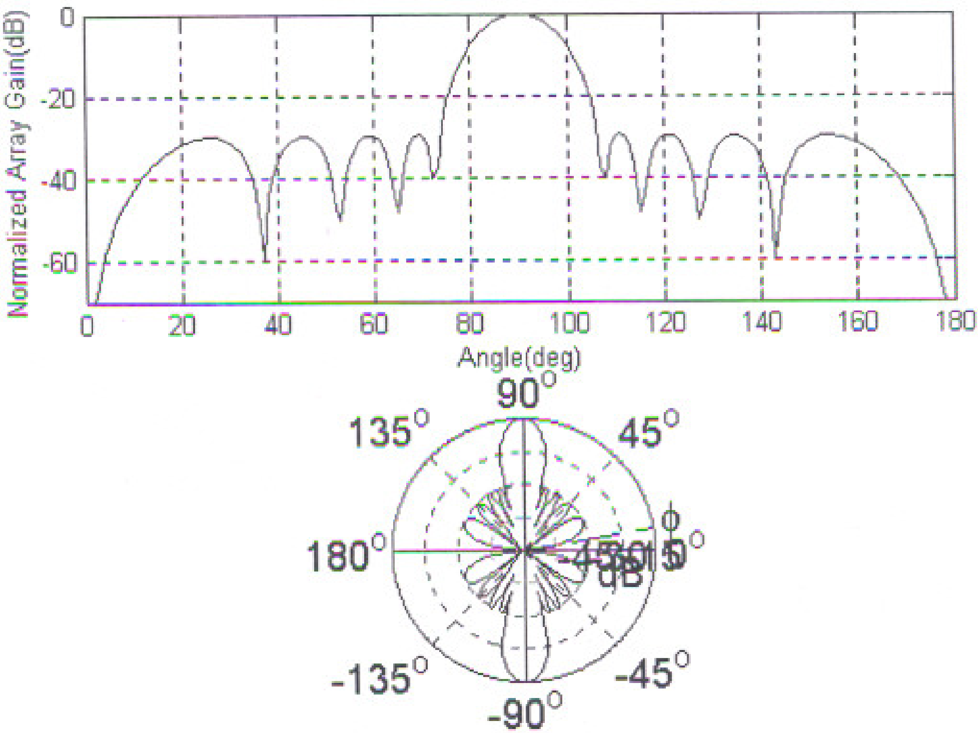


Figure 3.3(c): Pattern of linear array for N=10, d=λ/2 after 2nd iteration.

(b) **No of elements in array** = 10,
Error =0.005,
No of iteration required=3,
Total time taken = 28.78seconds

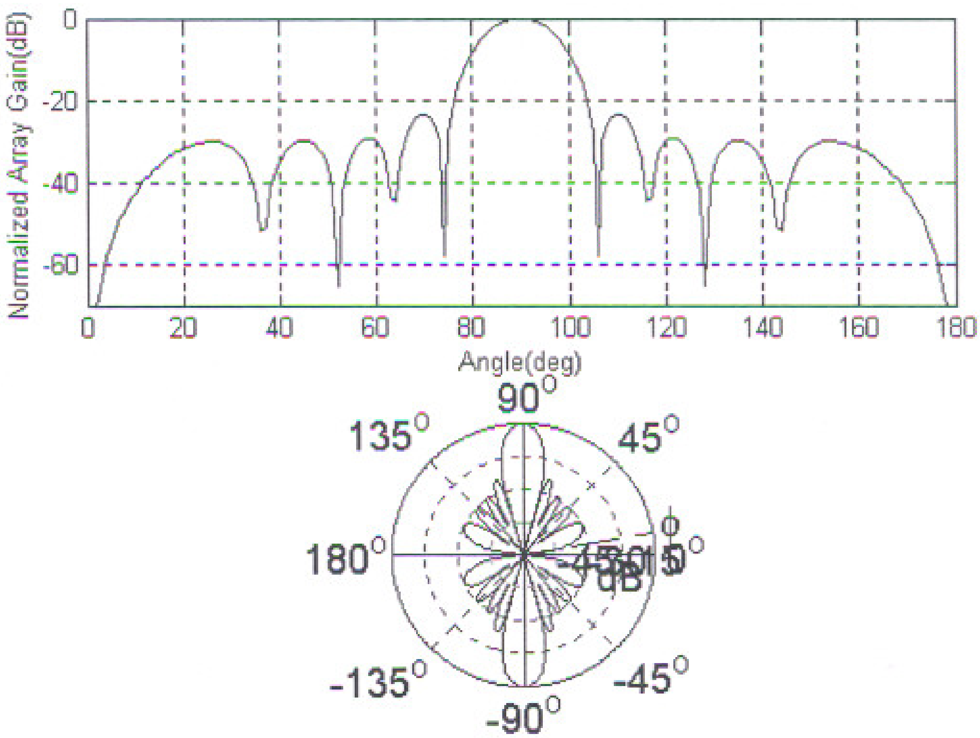


Figure 3.4(a): Pattern of linear array for N=10, d=λ/2 after 1st iteration.

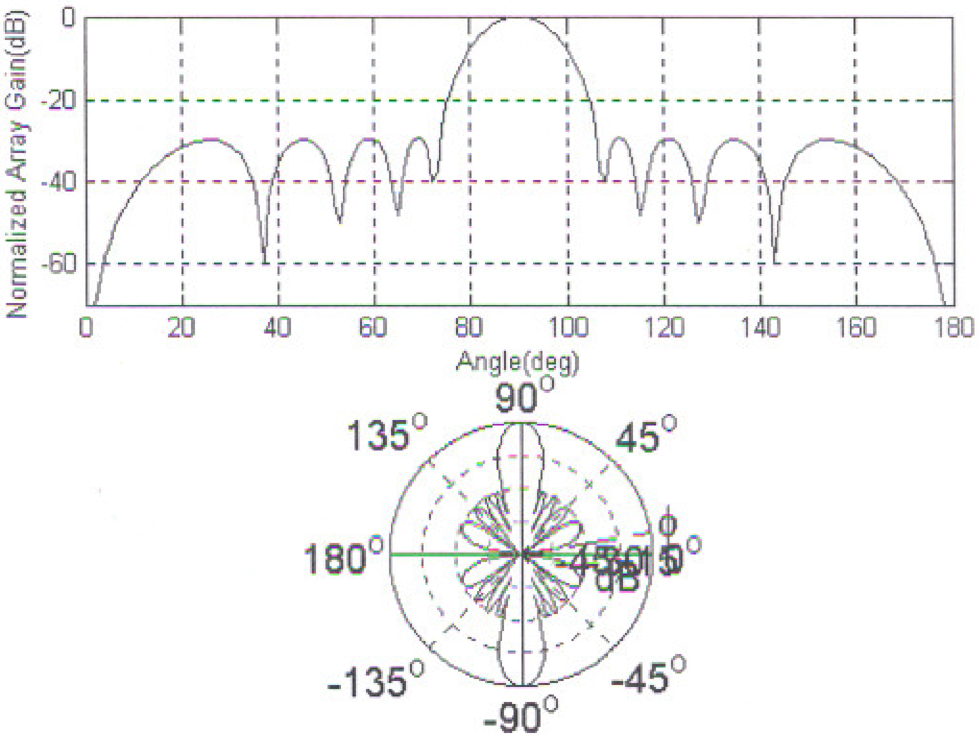


Figure 3.4(b): Pattern of linear array for N=10, d=λ/2 after 2nd iteration.

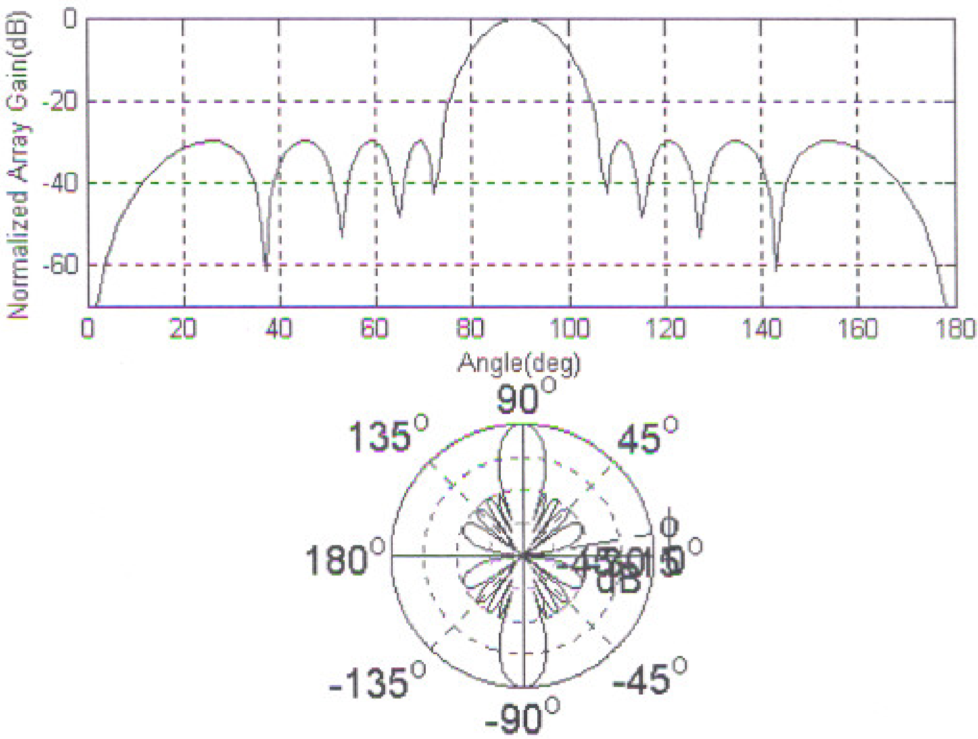


Figure 3.4(c): Pattern of linear array for N=10, d=λ/2 after 3[rd] iteration.

or

Pattern of linear array for N=10, d=λ/2 at error 0.05

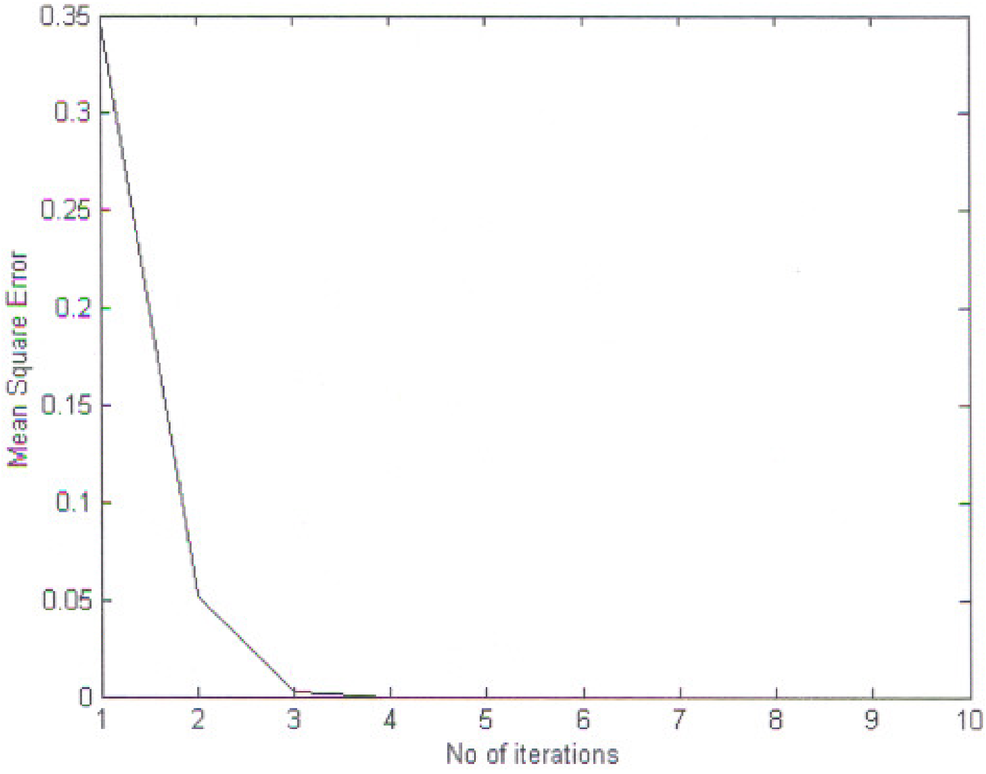


Figure 3.4(d): Error Graph showing the convergence for N=10

2. **(a)** **No of elements in array** = 16,
Error =0.5,
No of iteration required=1,
Total time taken = 17.6seconds

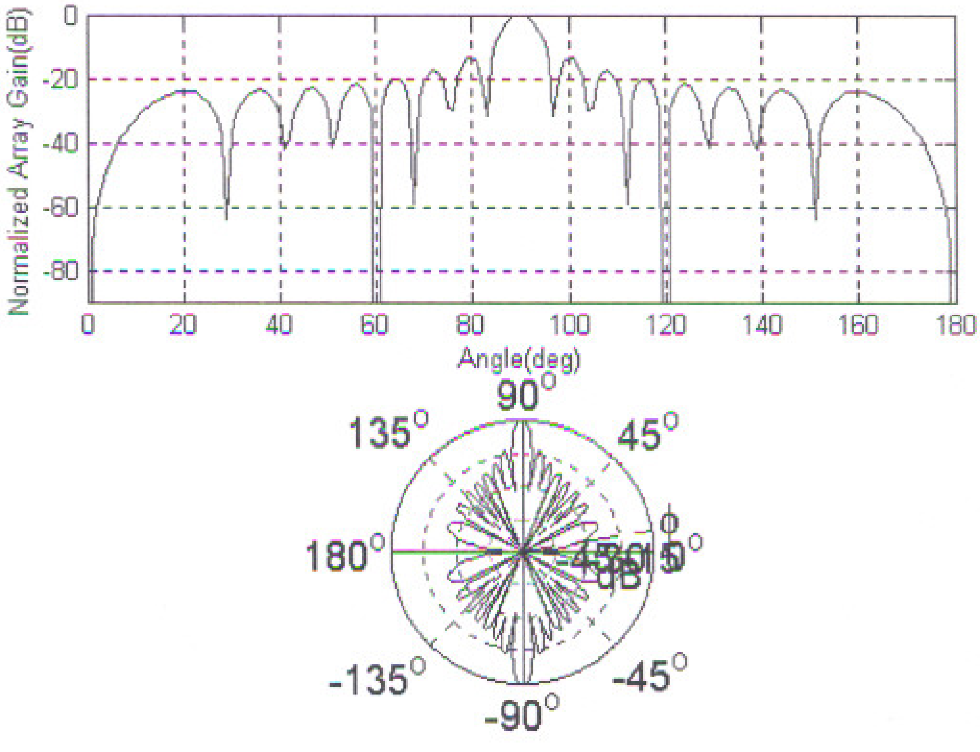


Figure 3.5(a): Pattern of linear array for N=16, d=λ/2

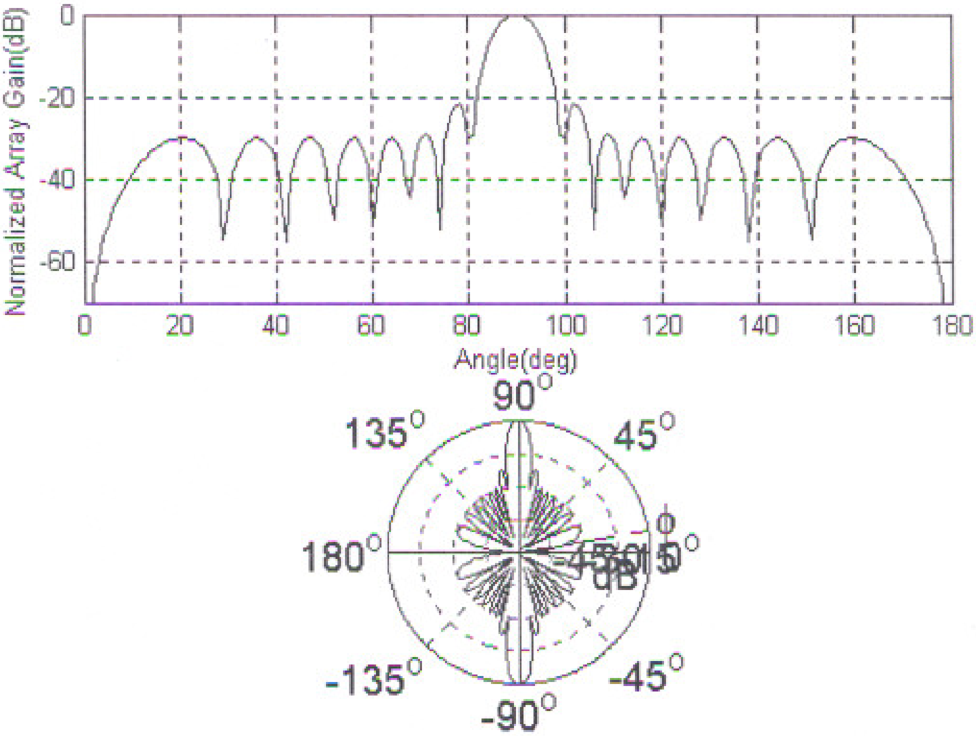


Figure 3.5(b): Pattern of linear array for N=16, d=λ/2 at error 0.5

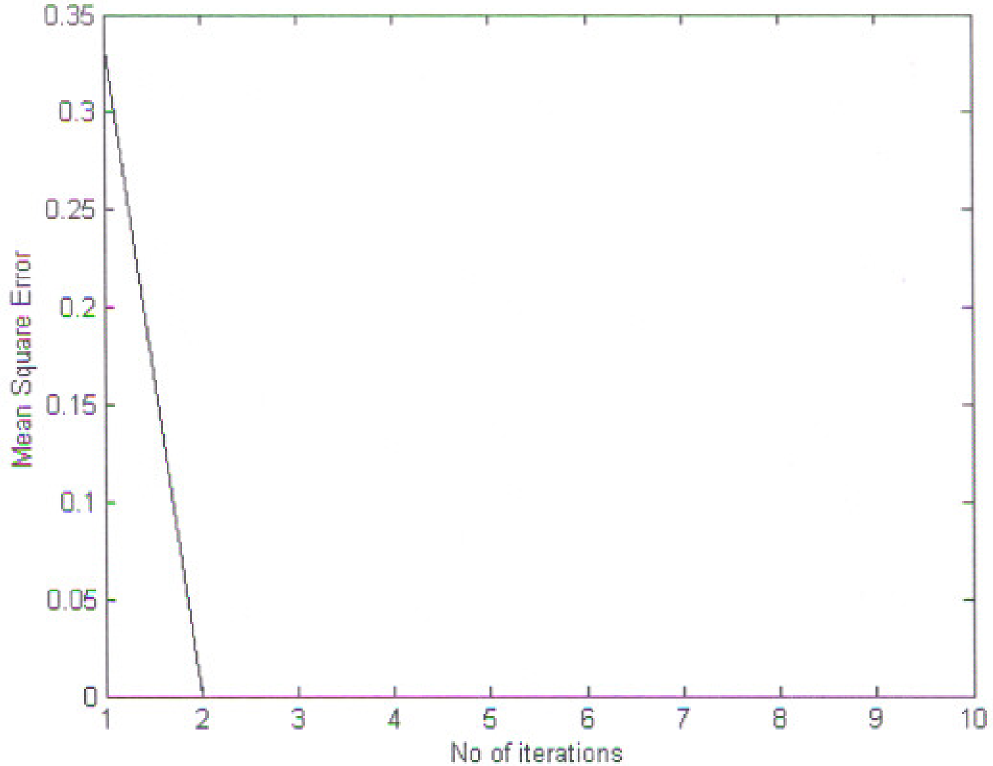


Figure 3.5(c): Error (up to 0.5) Graph showing the convergence for N=16

(b) Error =0.005,
No of iteration required=2,
Total time taken = 22.08seconds

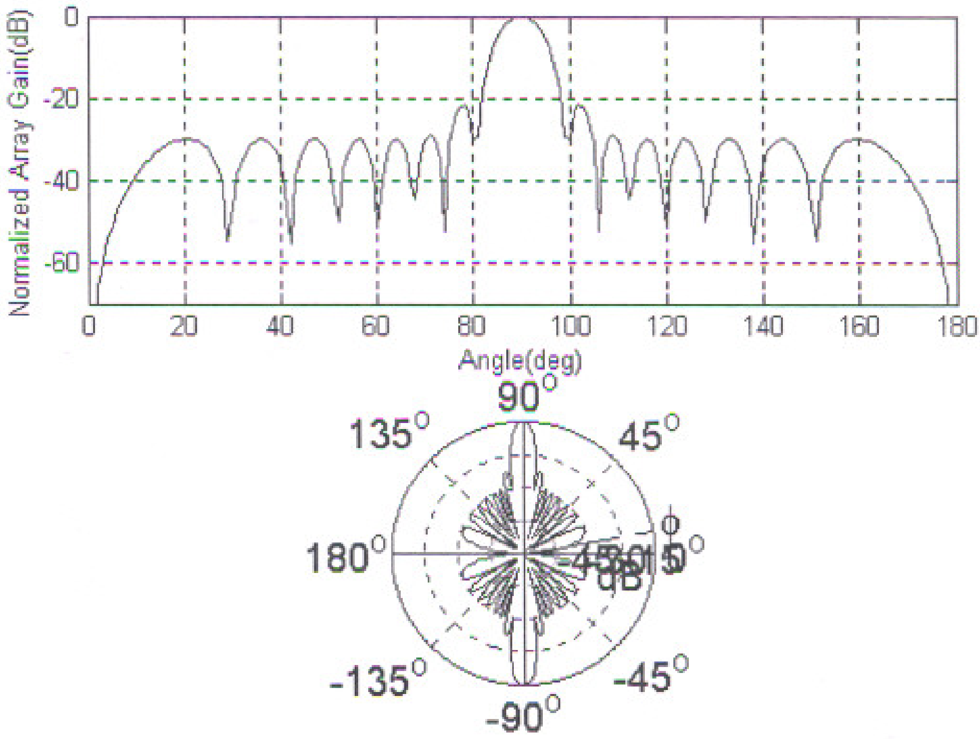


Figure 3.6(a): Pattern of linear array for N=16, d=λ/2 at 1st iteration.

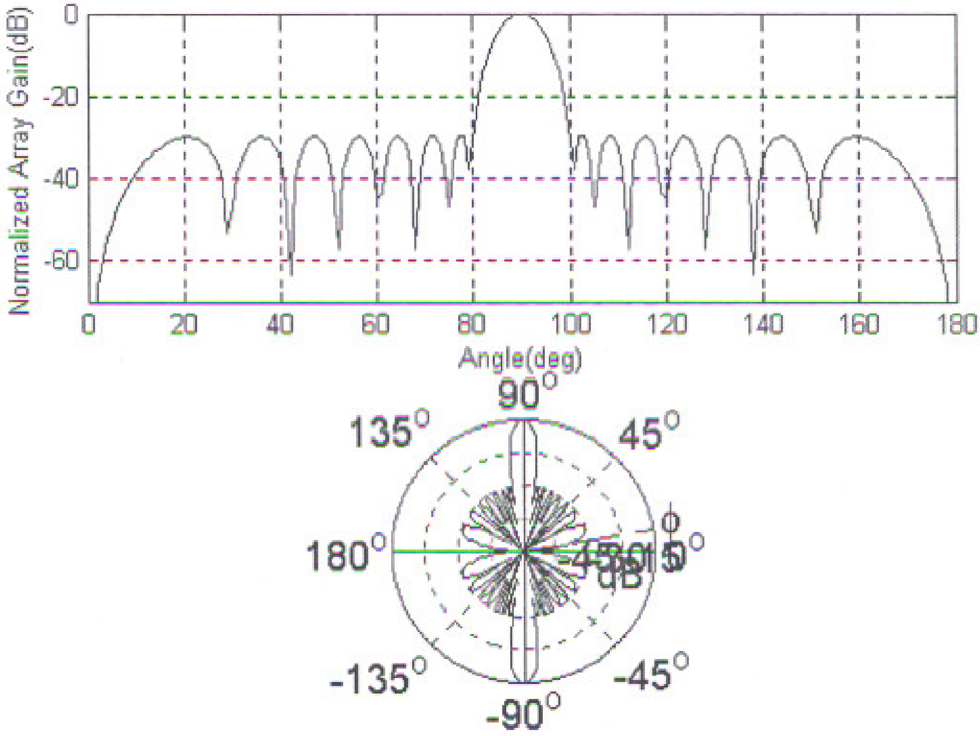


Figure 3.6(b): Pattern of linear array for N=16, d=λ/2 at 2nd iteration i.e. at error 0.005

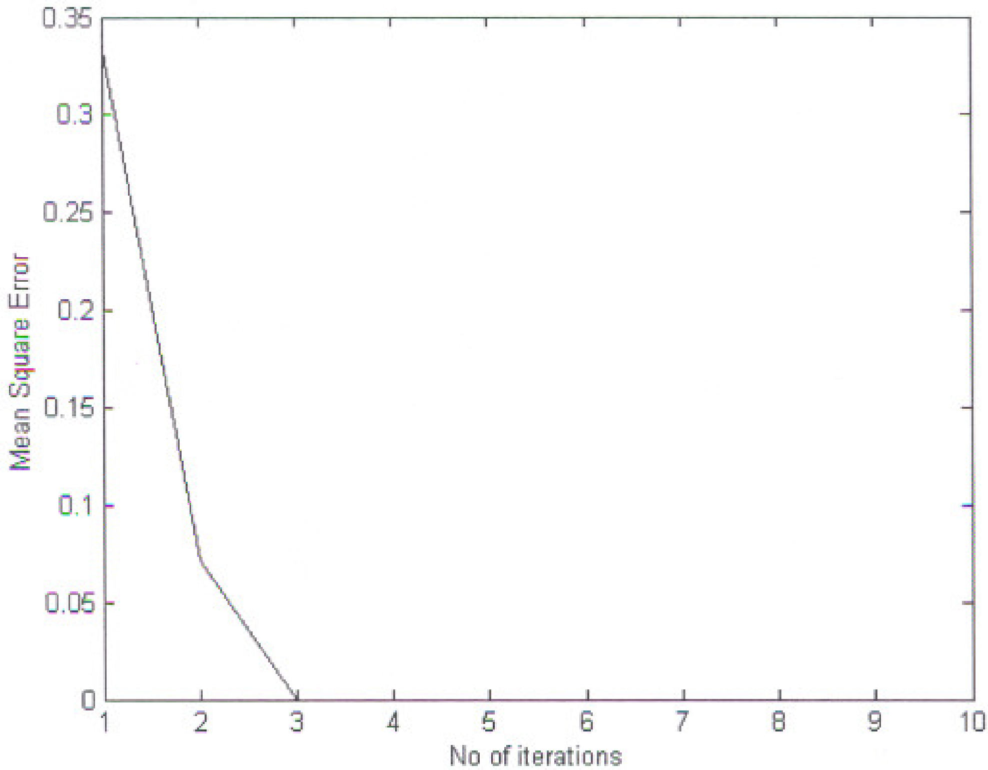


Figure 3.6(c): Error (0.005) Graph showing the convergence for N=16

3. (a) **No of elements in array** = 20,
Error =0.5,
No of iteration required=1,
Total time taken = 10.93seconds

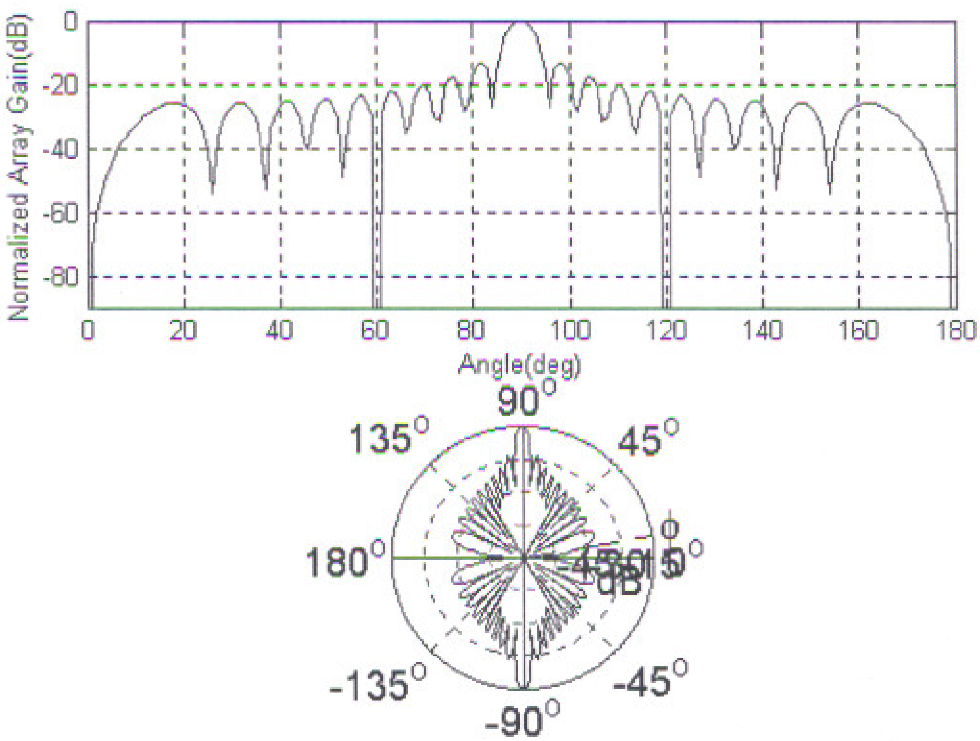


Figure 3.7(a): Pattern of linear array for N=20, d=λ/2

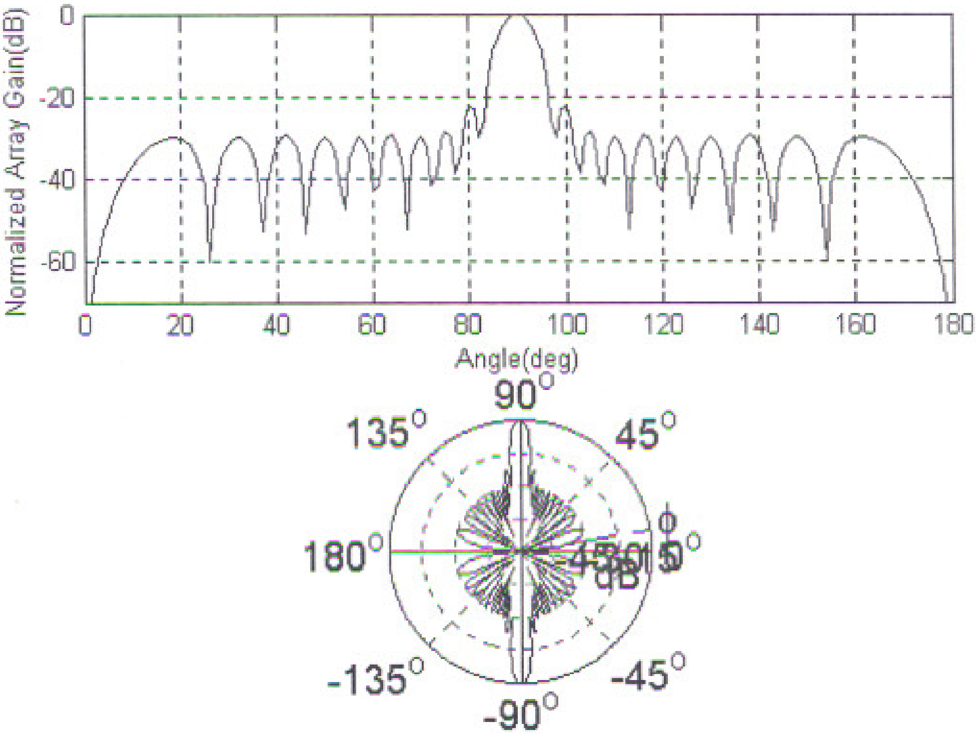


Figure 3.7(b): Pattern of linear array for N=20, d=λ/2 at 1st iteration or at error 0.5.

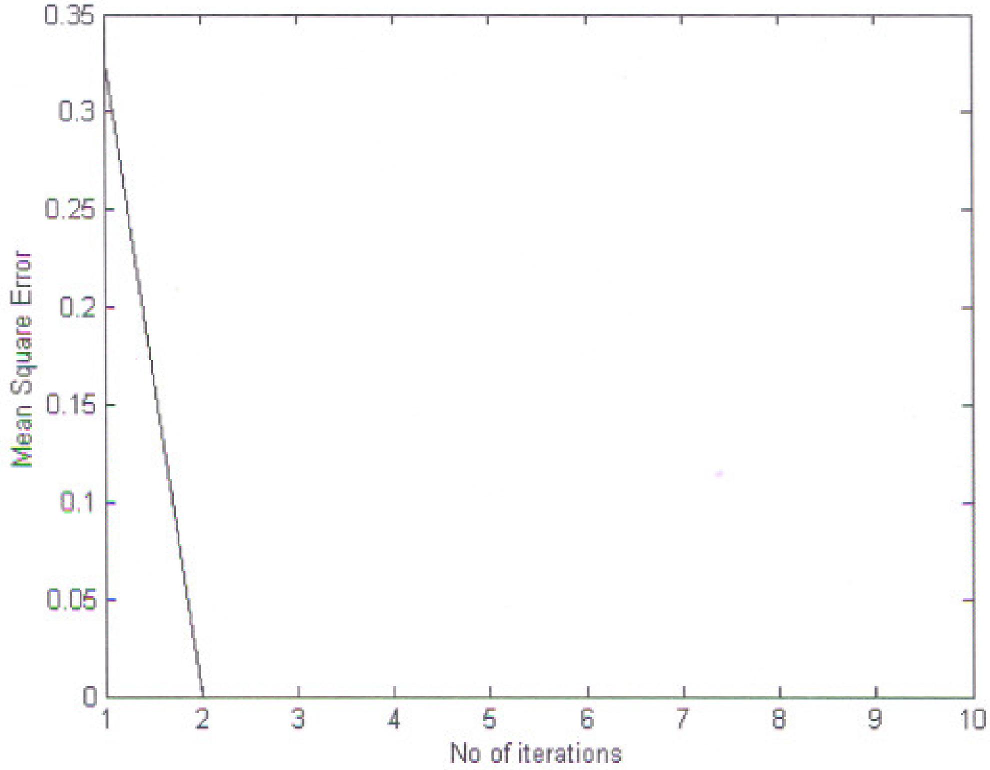


Figure 3.7(c): Error (0.5) Graph showing the convergence for N=20

(b) Error =0.005,
No of iteration required=2,
Total time taken = 22.8seconds

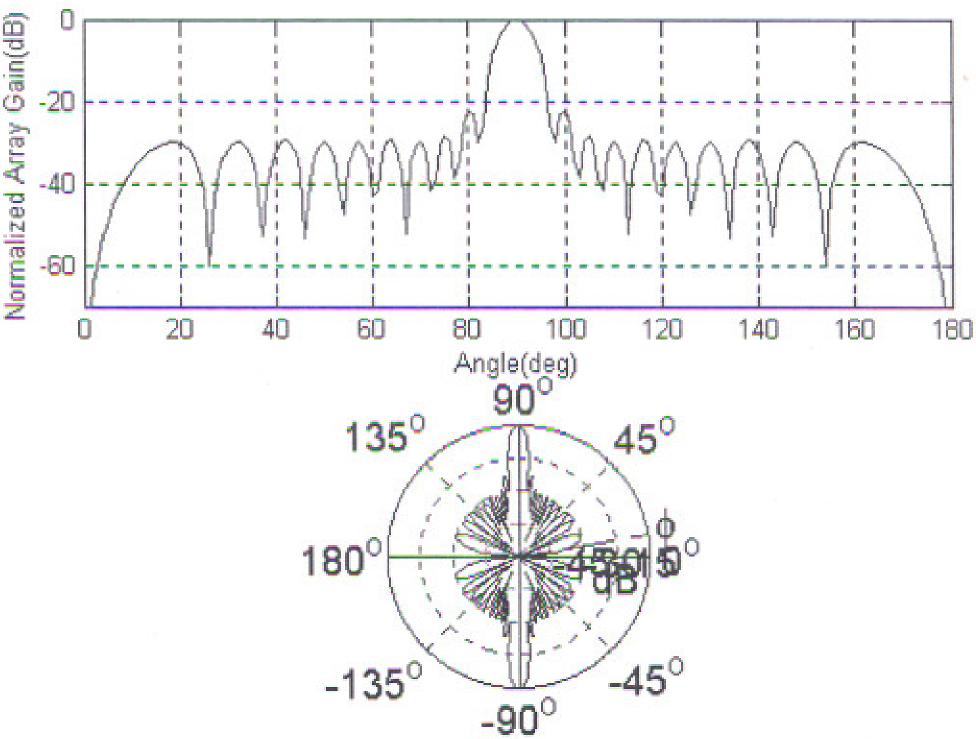


Figure 3.8(a): Pattern of linear array for N=20, d=λ/2 at 1st iteration

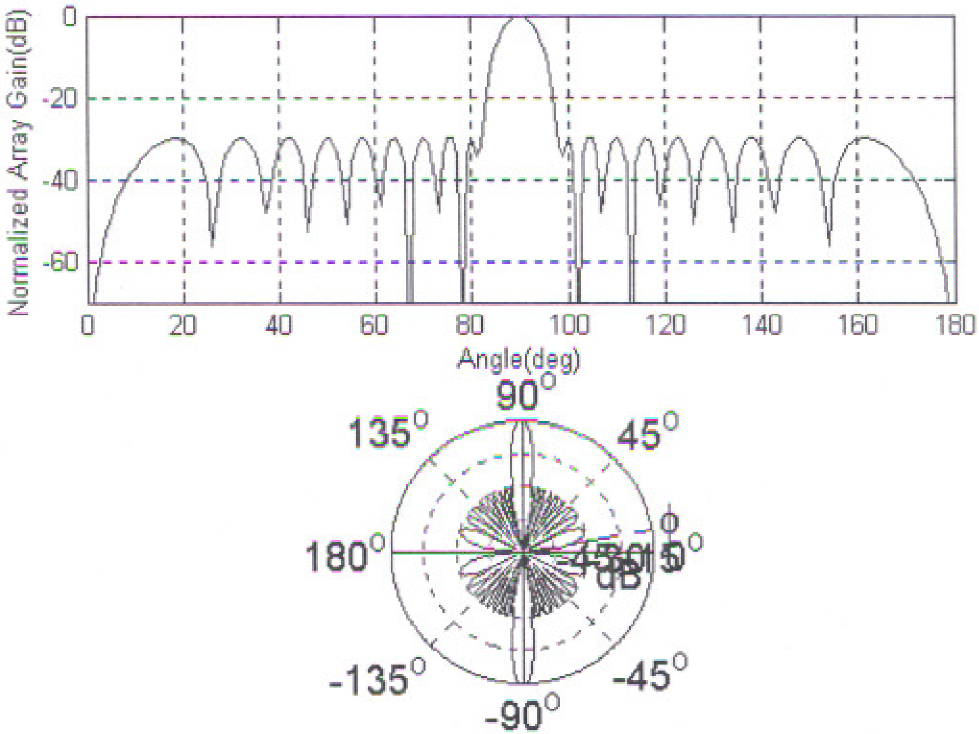


Figure 3.8(b): Pattern of linear array for N=20, d=λ/2 at 2nd iteration or at error 0.005.

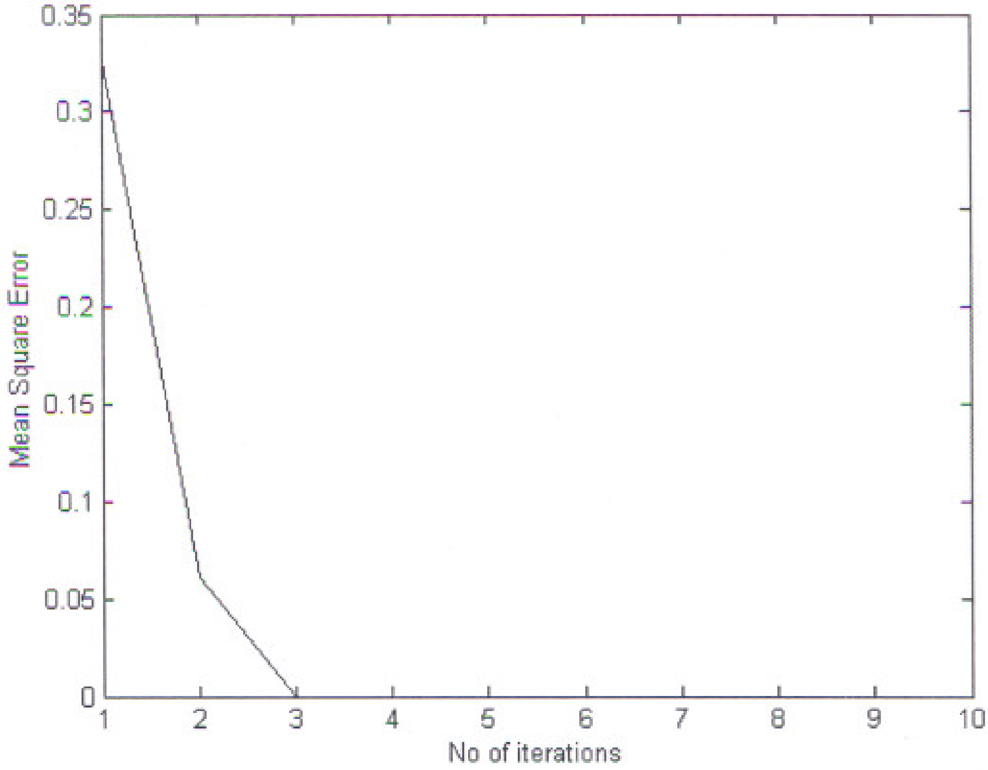


Figure 3.8(c): Error (0.005) Graph showing the convergence for N=20.

Null Formation:

This algorithm is also used for forming nulls in the desired direction. In CDMA systems, interference is also reduced, by placing the nulls in the pattern in the corresponding known directions of the interferers when number of interferers is large. As shown in Figure3.9, nulls lie over the sector 0.18 to 0.26, the interfering mobiles lying in region has no effect on desired signal as the effect of interfering mobiles is cancelled by imposing nulls in this region. In Figure 3.10 nulls are imposed over the sector 0.5 to 0.55. Figure 3.12 shows four nulls imposed at $u = 0.22, 0.24, 0.26, 0.28$. Figure 3.13 shows eight nulls lies over the sector 0.22 to 0.36. From this it is evident that in mobile communication systems interference is reduced, by imposing broad nulls in the direction of interferers.

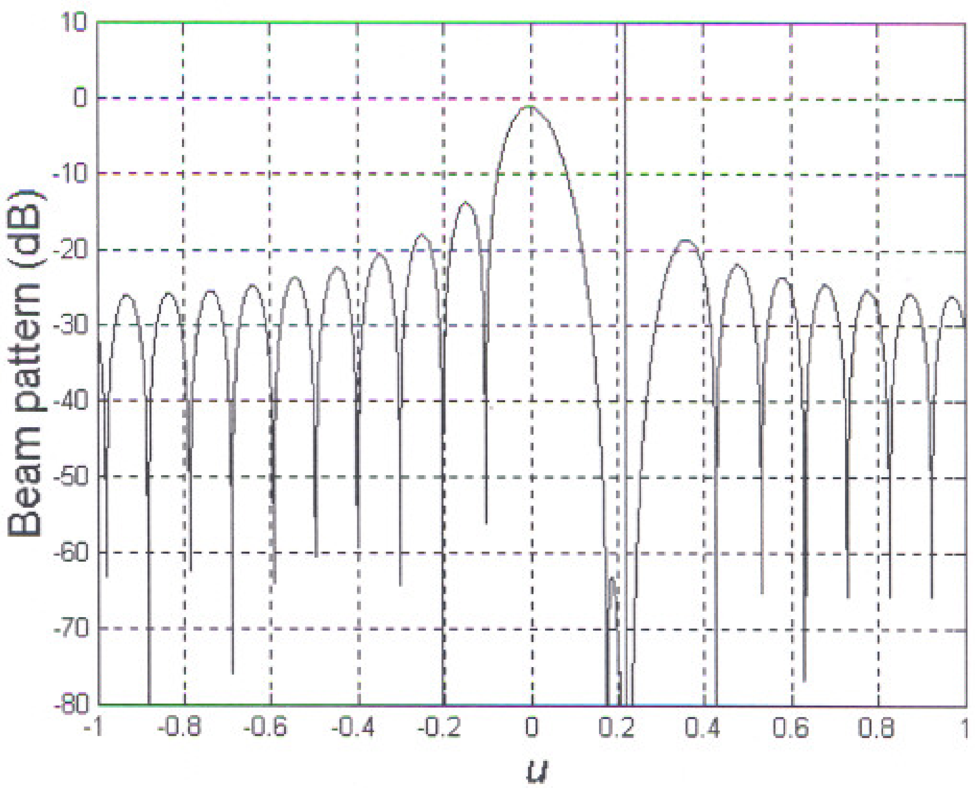


Figure 3.9.Three nulls imposed over the sector (0.18, 0.26), $2N+1=21$.

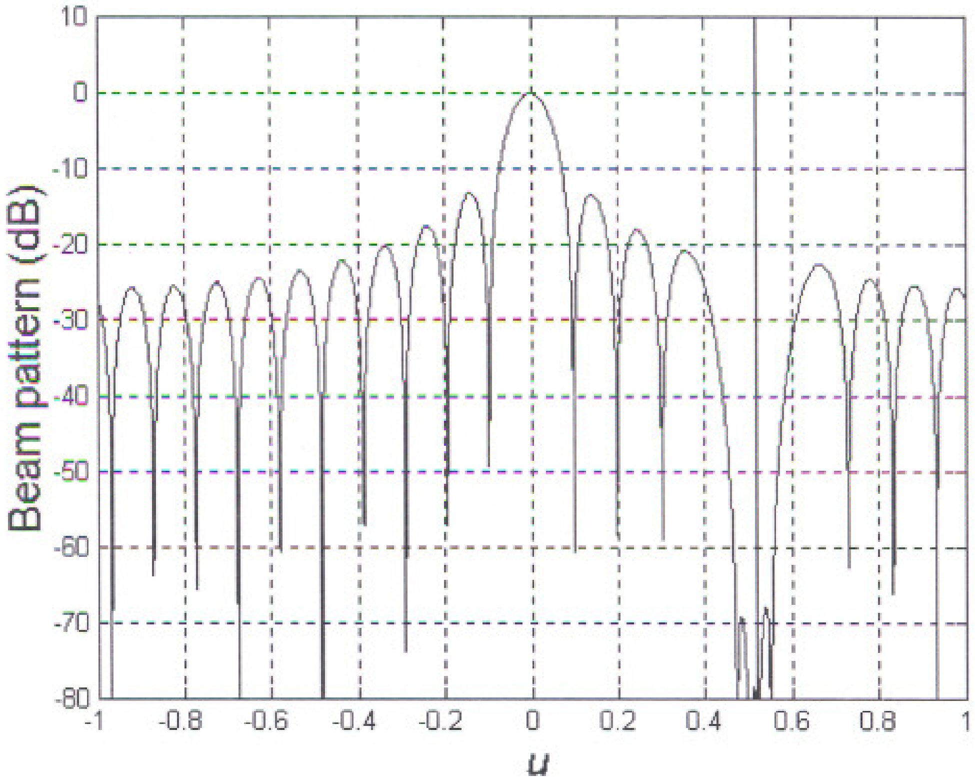


Figure 3.10. Nulls imposed over the sector (0.5, 0.55), $2N+1=21$

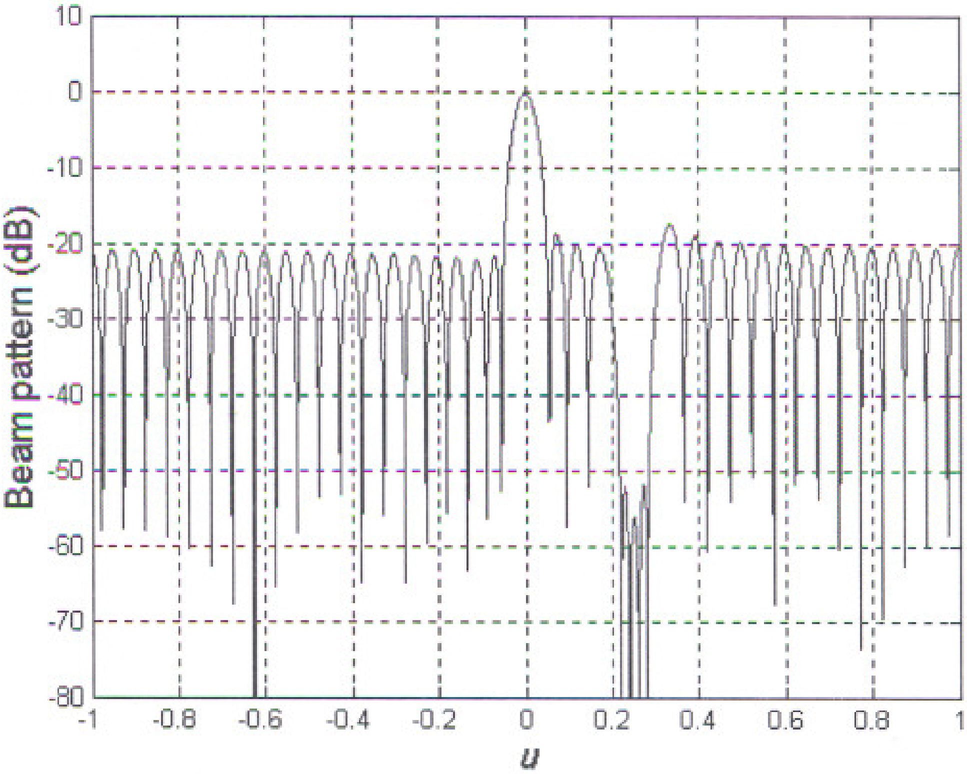


Figure 3.11. Perturbed 20dB Chebychev pattern with four nulls imposed at $u = 0.22, 0.24, 0.26, 0.28$, $2N+1=41$, $d=\lambda/2$.

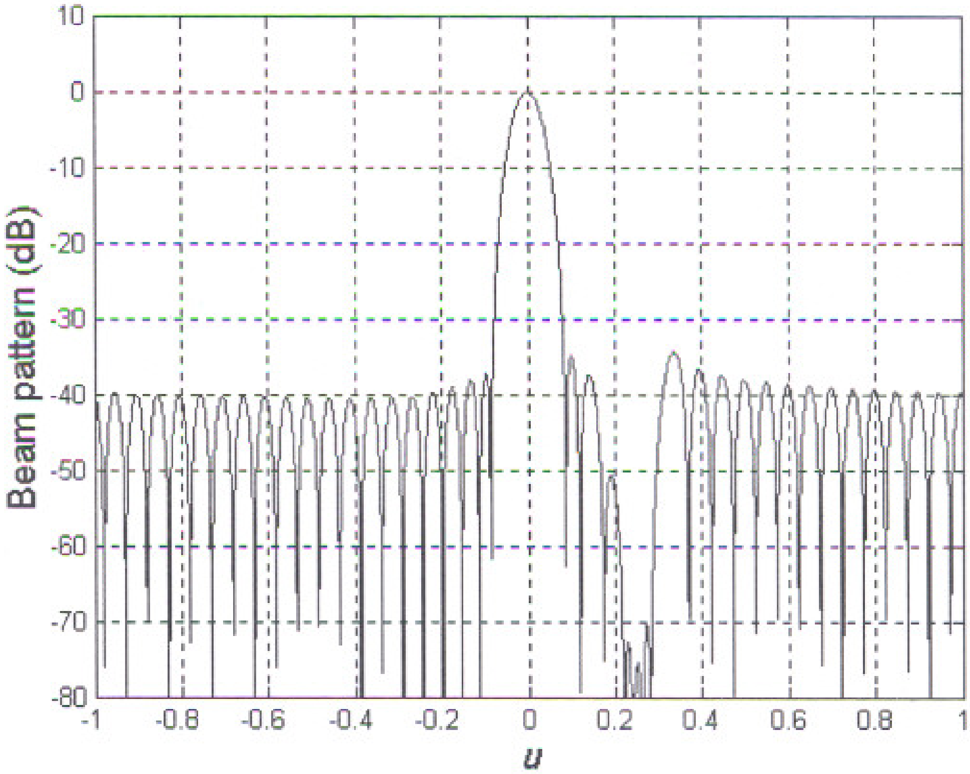


Figure 3.12. Perturbed 40 dB Chebychev pattern with four nulls imposed at $u = 0.22, 0.24, 0.26, 0.28$, $2N+1=41$, $d=\lambda/2$.

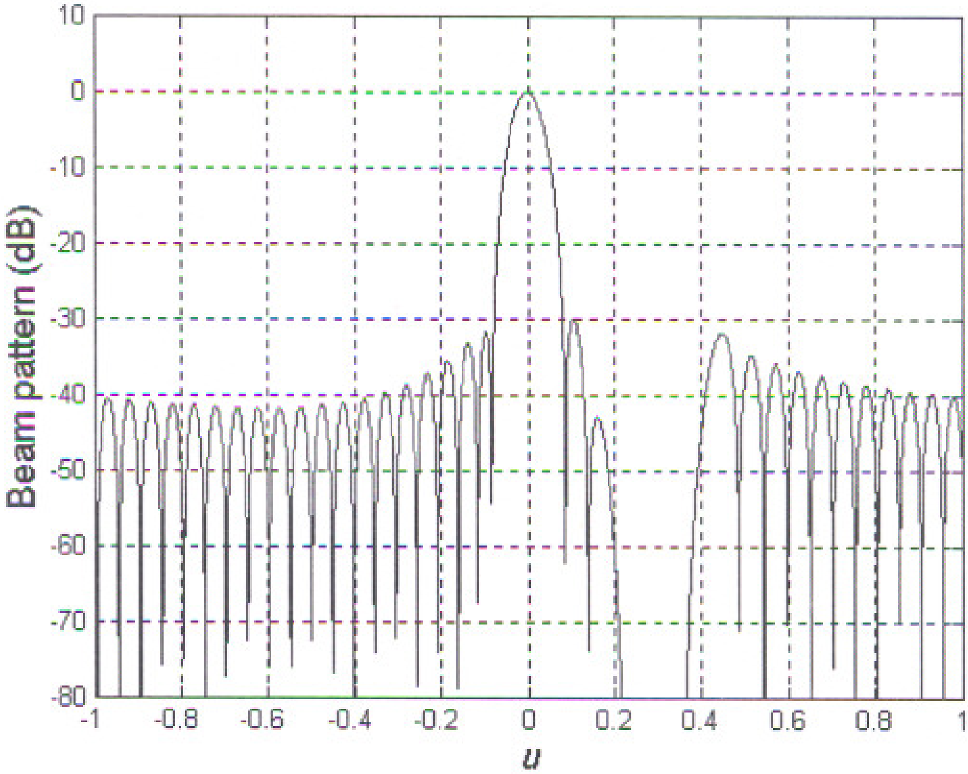


Figure 3.13. Perturbed 40 dB Chebychev pattern with eight nulls imposed at $u = 0.22, 0.24, 0.26, 0.28, 0.3, 0.32, 0.34, 0.36$, $2N+1 = 41$, $d = \lambda/2$.

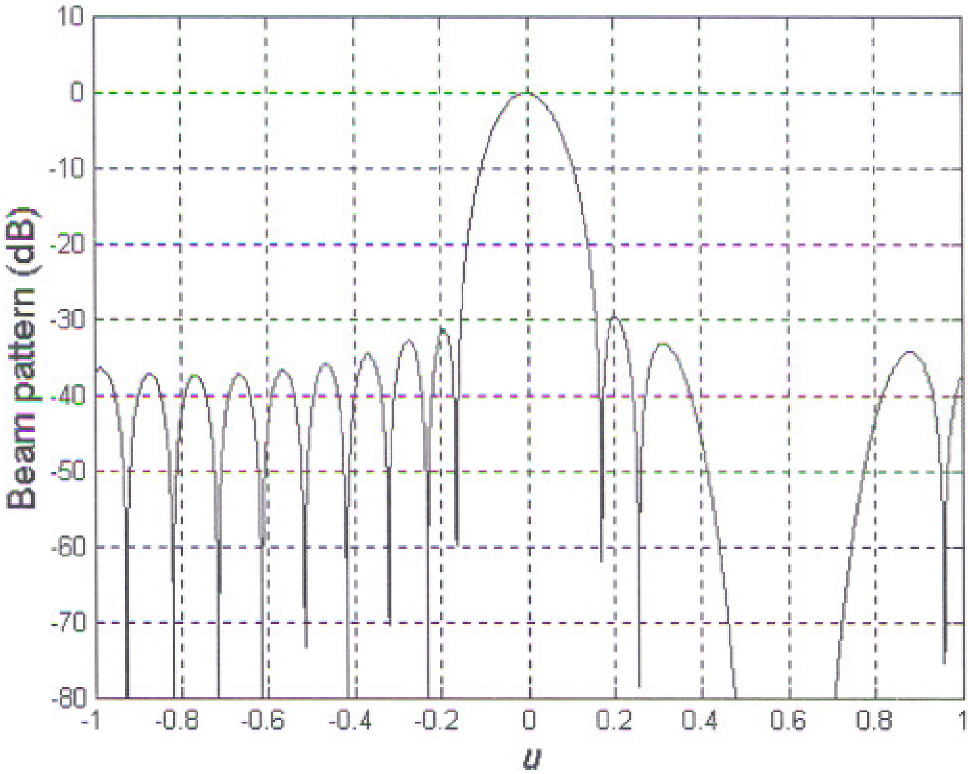


Figure 3.14. Perturbed 40 dB Chebychev pattern with eight nulls imposed over sector 0.52 to 0.66, $2N+1=21$, $d=\lambda/2$.

Chapter 4

Effect of Proposed Algorithm on Carrier Interference Ratio

In this chapter, effect of proposed algorithm on carrier interference ratio (CIR) is discussed. There is reduction in interference power by proposed algorithm presenting low sidelobe levels to the undesired users leads to direct and increase in Carrier to Interference ratio (CIR).

4.1 Observations and conclusion

Carrier interference ratio (CIR) [25] is defined as ratio of carrier power to interferer power. Mathematically [26] it can be represented as:

$$CIR = \frac{Carrier\ power}{Signal\ power} = \frac{Signal\ power}{Noise\ power + \sum_{k=1}^{N} I_0}$$

where I_0 represents the interferer power and number of interferers can vary from 1 to N.

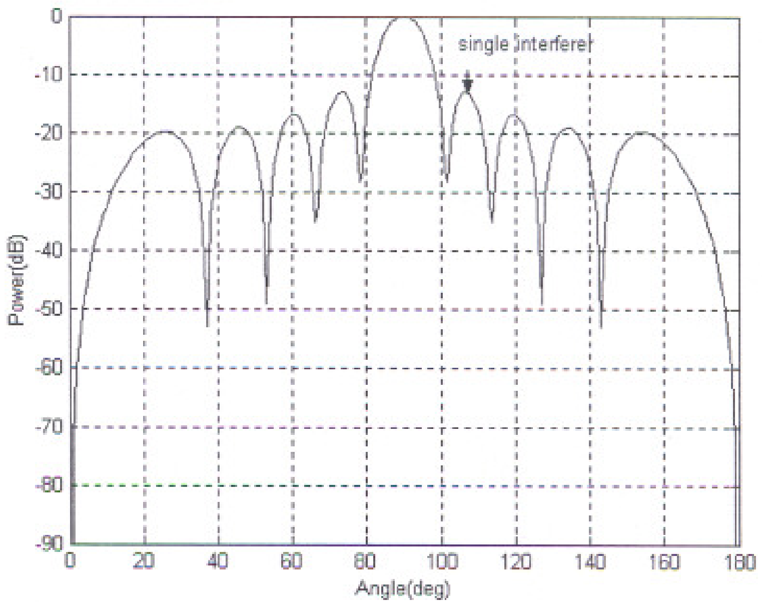


Figure 4.1 Interferer power before implementation of proposed algorithm.

Here we have assumed signal power to be 40dB. As shown in Figure 4.1, if we consider single interferer which lies at first sidelobe where its power is (-12dB). Then we calculate the interferer power i.e. 40-12=28dB as we have assumes signal power 40dB. Now CIR ratio comes out to be 1.42dB.

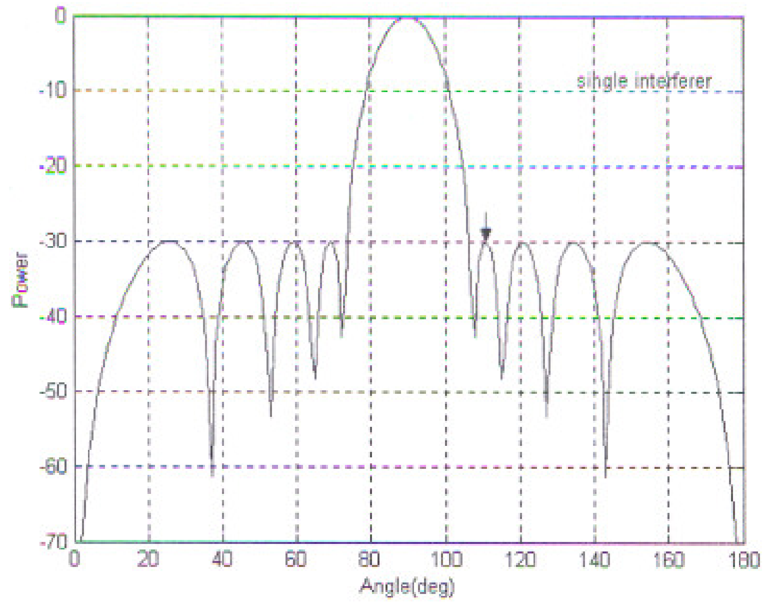


Figure 4.2 Interferer power at final iteration of proposed algorithm.

In the similar manner we have calculated the interferer power as shown in Table 4.1, for each iteration of proposed algorithm. Figure 4.2 shows the equal sidelobes, where power of interferer is (40-30=10 dB). CIR in this case is 4dB. In the similar manner we have calculated CIR shown in Table 4.2 for different number of interferers. Figure 4.3 and Figure 4.4 show the positions of 5 and 10 interferers respectively.

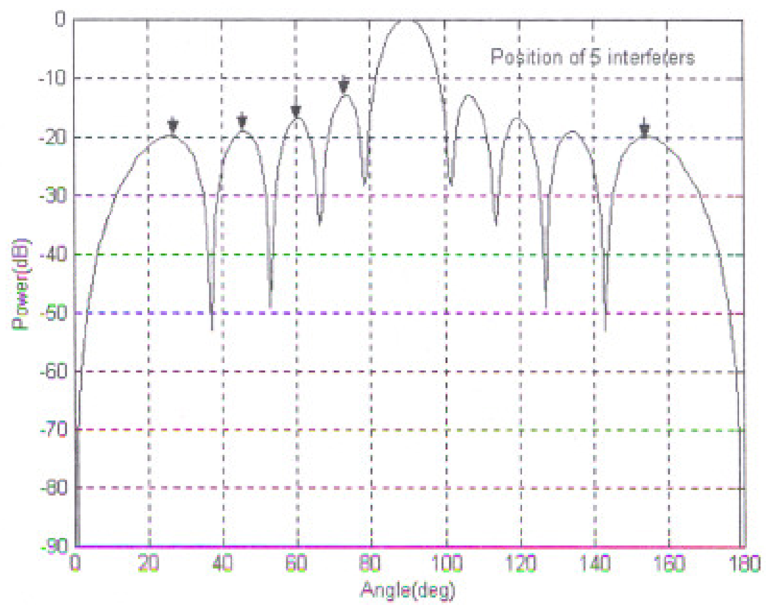


Figure 4.3 Graph showing position of 5 interferers

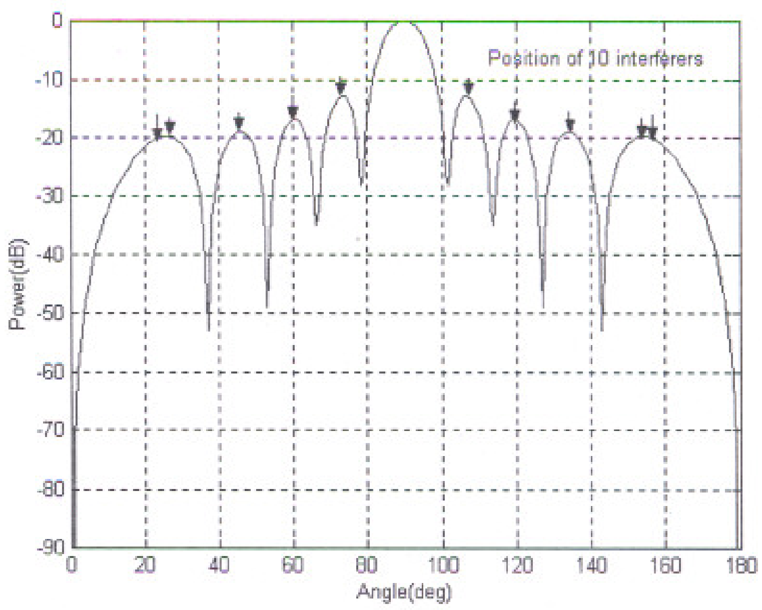


Figure 4.4 Graph showing position of 10 interferers

Table4.1: The initial power and power after iterations of proposed algorithm for different number of interferers.

No. of interferers	Interferer power initially (dB)	Interferer power after 1st iteration (dB)	Interferer power after 2nd iteration (dB)	Interferer power after 3rd iteration (dB)
1	28	17	12	10
2	51	28	21	20
3	73	38	31	30
4	92	48	41	40
5	112	58	51	50
8	184	96	82	80
10	225	116	102	100

It is evident from Table 4.1 that there is reduction in interference power by proposed algorithm, for example for 5 interferers initial inference power is 112dB. Interference power reduces to 58dB after 1st iteration. It further decreases to 51dB after 2nd iteration. Interference power at equal side lobes is 50dB.

Table 4.2: CIR for different number of interferers for proposed algorithm.

No. of interferers	Initial CIR	CIR after 1st iteration (dB)	CIR after 2nd iteration (dB)	CIR after 3rd iteration (dB)
1	1.42	2.5	3.4	4
2	0.8	1.42	1.9	2
3	0.5	1.05	1.29	1.33
4	0.4	0.83	0.97	1
5	0.32	0.62	0.78	0.8
8	0.217	0.42	0.48	0.5
10	0.175	0.34	0.39	0.4

Due to this there is increase in CIR, this is evident from Table 4.2, in this for 5 interferers initially CIR is 0.32 dB. After 1st iteration it increases to 0.62 dB, 0.72 dB for 2nd iteration and 0.8dB for final iteration. This is also evident from Figure 4.5, Figure 4.6, Figure 4.7, Figure 4.8 and Figure 4.9 that proposed algorithm reduces the interference power for every iteration and increases the CIR. It is also seen from Table 4.2 and Figure 4.11that as the number of interferer's increases, CIR decreases.

It is concluded that there is reduction in interference power by proposed algorithm that is presenting low sidelobe levels to the undesired users leads to direct and increase in Carrier to Interference ratio (CIR).

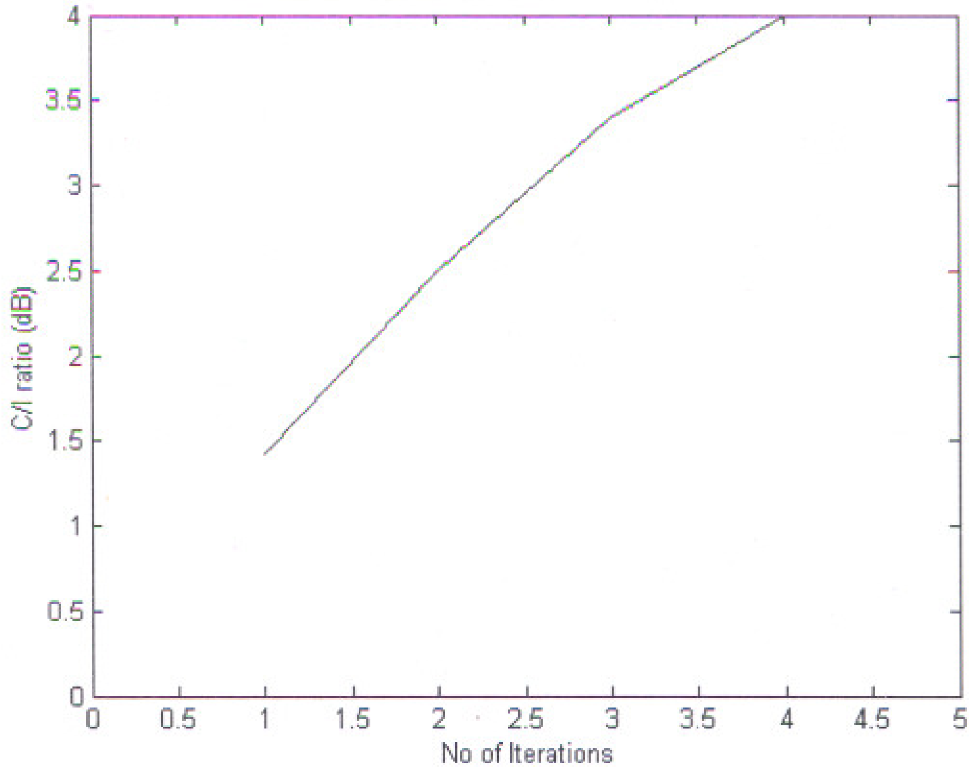


Figure 4.5: Graph showing increase in CIR ratio for single interferer by proposed algorithm.

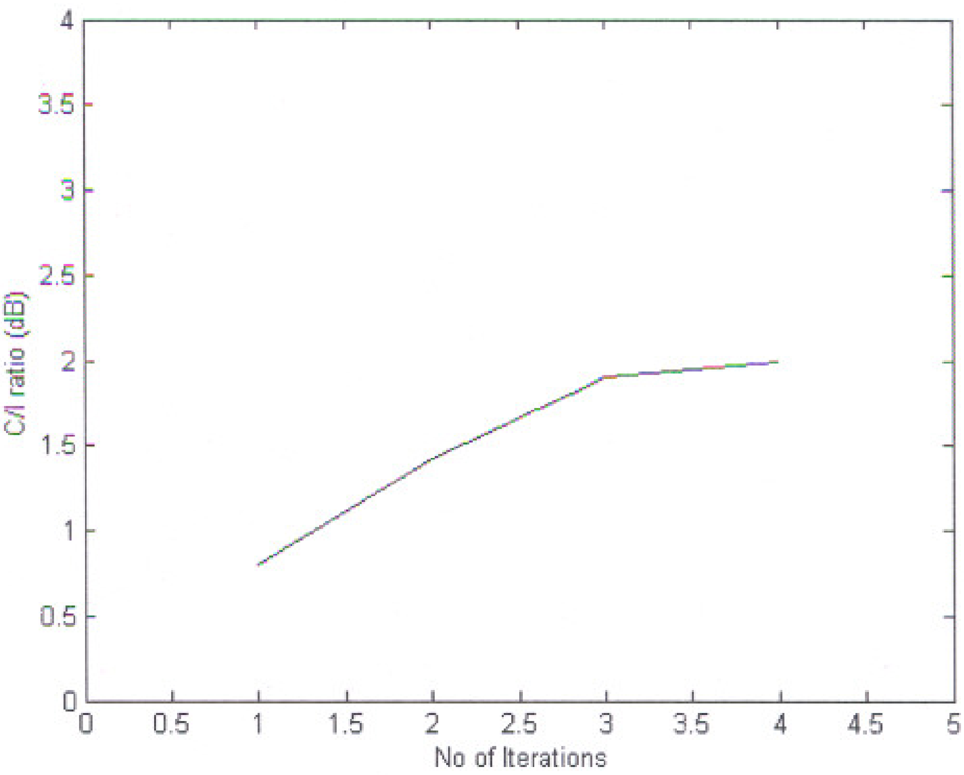


Figure 4.6: Graph showing increase in CIR ratio for 2 interferers by proposed algorithm.

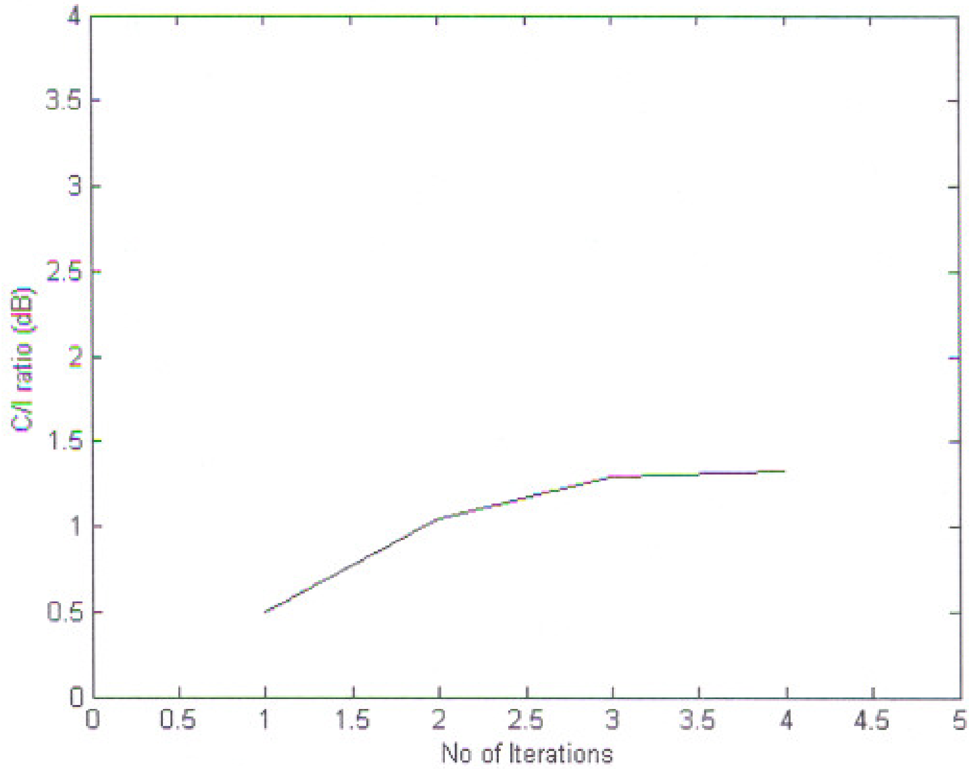


Figure 4.7: Graph showing increase in CIR ratio for 3 interferers by proposed algorithm.

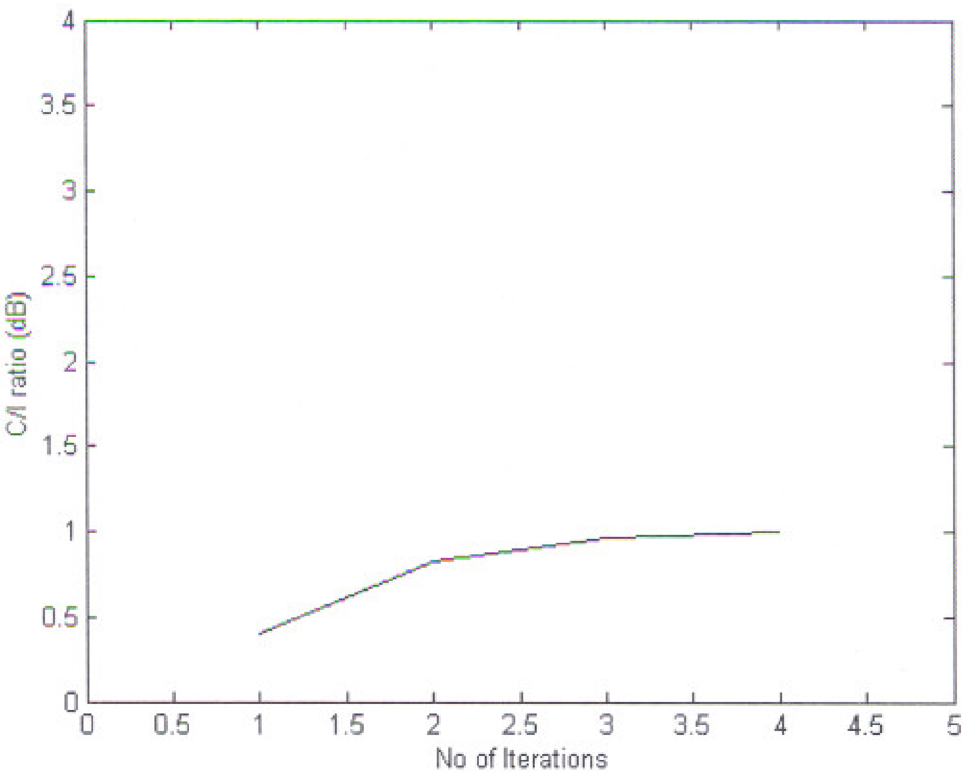


Figure 4.8: Graph showing increase in CIR ratio for 4 interferers by proposed algorithm.

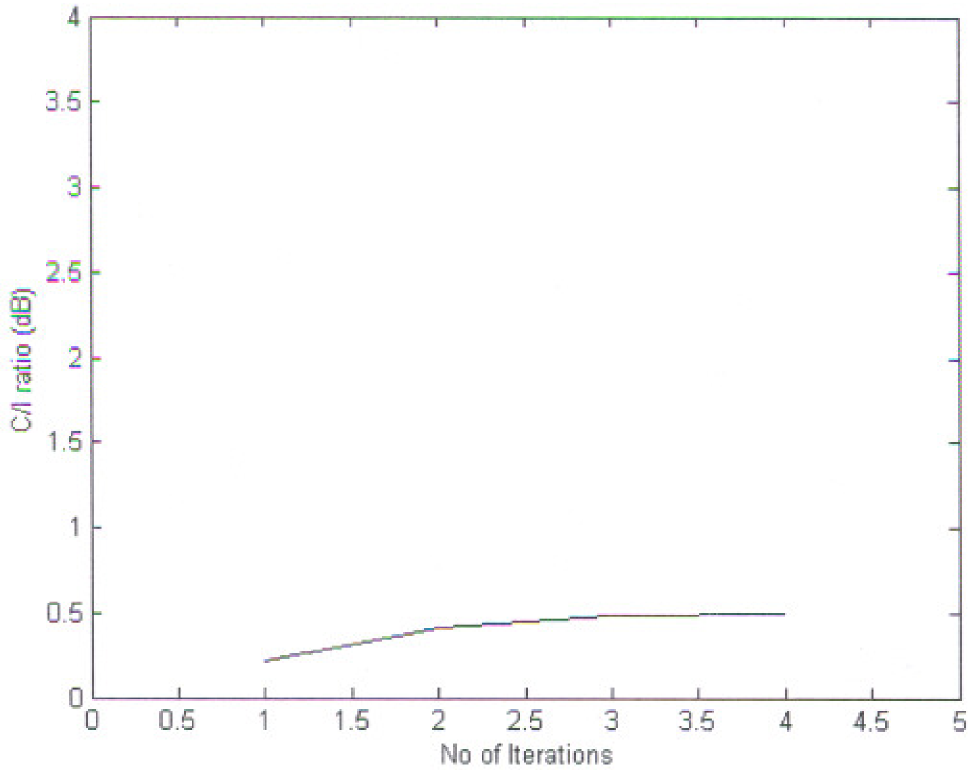


Figure 4.9: Graph showing increase in CIR ratio for 8 interferers by proposed algorithm.

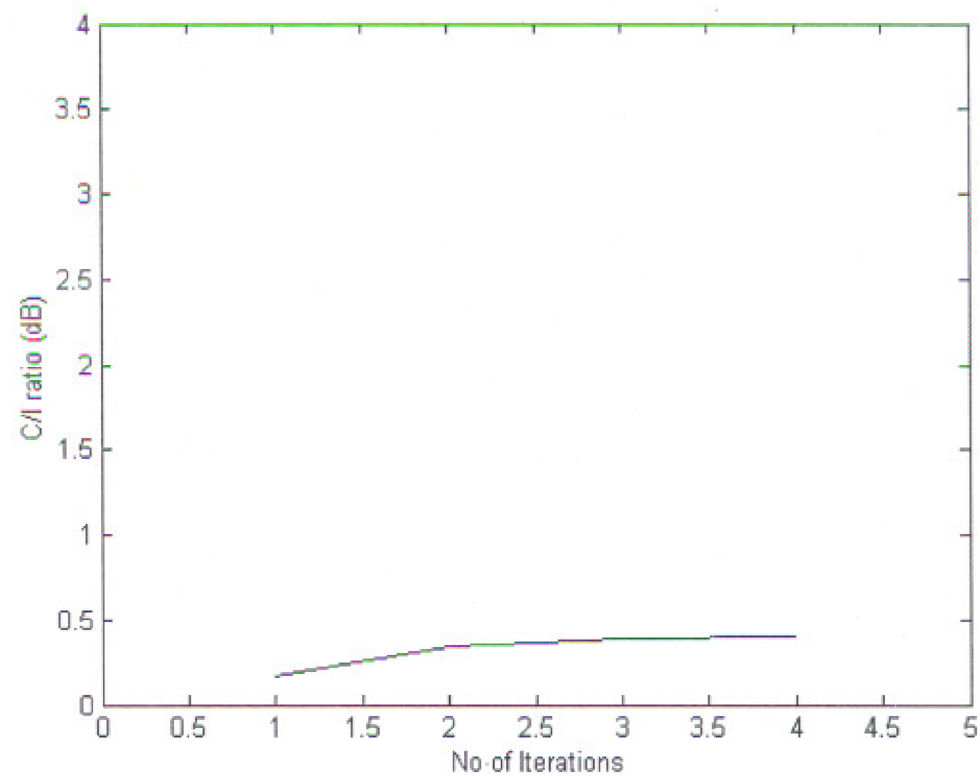


Figure 4.10: Graph showing increase in CIR ratio for 10 interferers by proposed algorithm

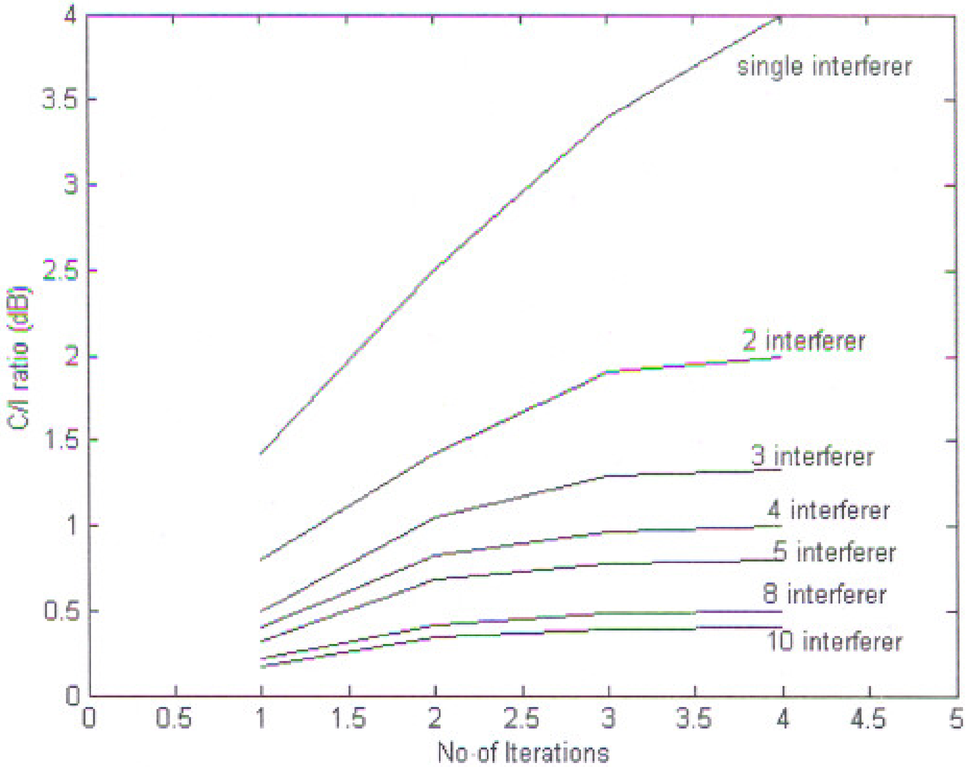


Figure 4.11: Graph showing increase in CIR ratio for different number of interferers by proposed algorithm

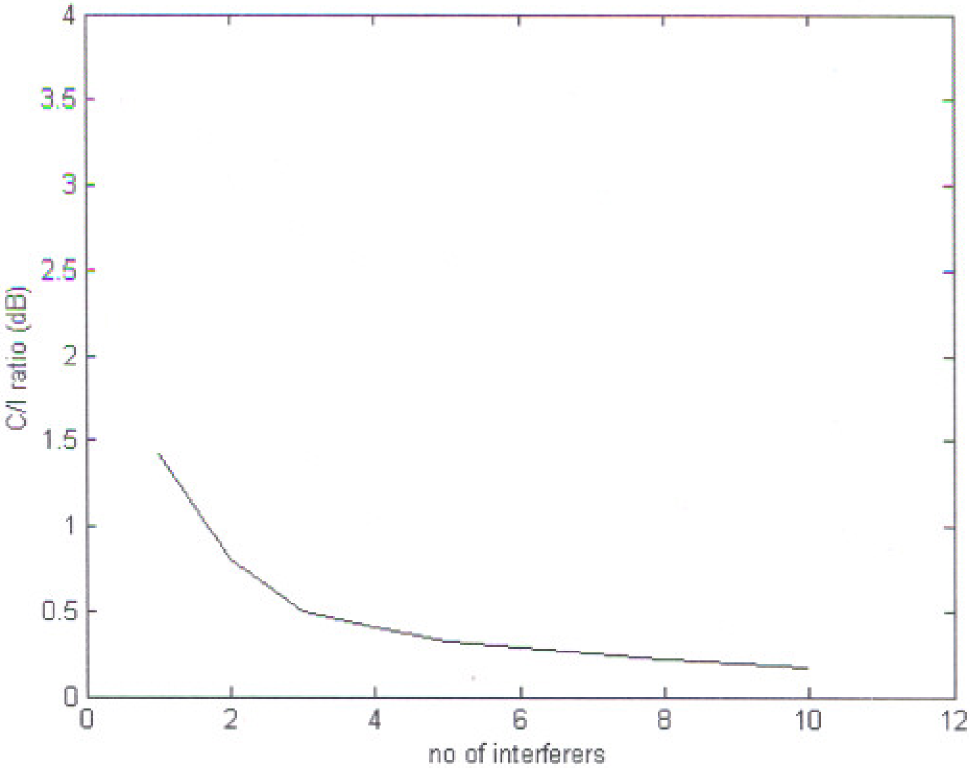


Figure 4.12 Graph showing the decrease in CIR as number of interferers increases.

Chapter 5

Conclusions & Future Scope

5.1 Conclusion

CDMA is an important method for the third generation wireless communication systems because of increase in number of simultaneous users. However, for CDMA to satisfy the needs for an increased number of simultaneous users, unwanted directional interferences, which degrade system performance should be reduced. Different antenna array techniques are to be used at transmitter or receiver, in order to reduce unwanted directional interferences. The described technique shows that a minimum phase difference of 1^0 can be taken to produce independent control of zero in directional pattern in antenna arrays. Phase difference less than 1^0 cannot form zeros in the directional pattern of antenna arrays. A new array pattern synthesis procedure is analyzed in which minimum mean square error is assigned externally and iterations continue and in each iteration sidelobe level decreases. This algorithms also forms nulls in the direction of interferes. Reduction in side lobe level decrease interference power of undesired users which leads to direct increase in Carrier to Interference ratio (CIR) as evident from Table5.1.

Table 5.1: CIR for different number of interferers.

No. of interferers	Initial CIR	CIR after final iteration (dB)
1	1.42	4
2	0.8	2
3	0.5	1.33
4	0.4	1
5	0.32	0.8
8	0.217	0.5
10	0.175	0.4

The major advantage of this procedure is its flexibility as minimum mean square error (MMSE) is user define. These capabilities can be exploited to improve the capacity and the performance of CDMA based wireless communication systems.

5.2 Future Scope

Mostly, equally spaced arrays are used for the transmitter requiring variable array pattern, but this synthesis procedure can be used with non-isotropic elements with arbitrary spacing. In future this can be employed in different array configuration to increase the capacity to a large extent. This is a software implementation; final testing using hardware can be done. In future null steering by controlling the element positions, in which independent steering of the main beam and nulls to arbitrary independent directions can be done.

References

[1] J. Bartolic, Z. Sipus, N. Herscovici, D. Bonefacic, and R. Zentner, " Planar and cylindrical microstrip patch antennas and array for wireless communications", *11th Int. Conf. on Antenna Propag.* , Conference Publication, No 480, pp. 569-573, April 2001.

[2] L. C. Godara," Application of antenna arrays to mobile communication, Part I: Performance improvement, feasibility, and system considerations", *Proc. IEEE*, vol. 85, no. 7, pp. 1031-1060, July 1997.

[3] L. C. Godara," Application of antenna arrays to mobile communication, Part II: Beam-forming, and direction-of-arrival considerations", *Proc. IEEE*, vol. 85, no. 8, pp. 1195-1245, August 1997.

[4] J.Litva and T.Kwok-Yeung Lo, " Digital Beamforming in Wireless Communication", John Wiley and Sons, New York, 1996.

[5] J.H.Winters,"Smart Antennas for Wireless Systems", IEEE Personal Communications Magazine, pp. 23-27, February 1998.

[6] C. Swales et alii, "The Performance Enhancement of Multibeam Adaptive Base-Station Antennas for Cellular Land Mobile Radio Systems," IEEE Trans. on Vehicular Technology, vol. 39, n. 1, February 1990, pp. 56-67.

[7] M. Tangemann et alii, "Introducing Adaptive Array Antenna Concepts in Mobile Communication Systems," in Proceedings RACE Mobile Communications Workshop, Amsterdam, The Netherlands, May 1994, pp. 714-727.

[8] B. X. Weis, "A Novel Algorithm for Flexible Beam forming for Adaptive Space Division Multiple Access Systems," PIMRC '94, pp.729a-729e.

[9] O. Nørklit, J. B. Andersen, "Mobile Radio Environments and Adaptive Arrays," PIMRC '94, pp. 725-728.

[10] A. F. Naguib, A. Paulraj, T. Kailath, "Capacity Improvement with Base-Station Antenna Arrays in Cellular CDMA," IEEE Transactions on Vehicular Technology, vol. 43, n. 3, August 1994, pp. 691-698.

[11] E. Buracchini et alii, "Performance analysis of a mobile system based on combined SDMA/CDMA access technique", IEEE ISSTA'96, 22-25/9/96, Mainz, Germany, pp.370-374.

[12] D. Karaminas & A. Manikas," Super resolution broad null beamforming for cochannel interference cancellation in mobile radio networks," IEEE transaction of Vehicular Technology, vol.43. No.3, pp. 687-697, May 2000.

[13] D.E. Dudgeon, " Fundamentals of digital array processing", Proceeding of the IEEE, vol.65, no.6, pp.98-104, June 1977.

[14] R. Kohno et al., " Combination of an adaptive array antenna and a canceller of Interference for Direct Sequence Spread spectrum multiple access system," IEEE JSAC, vol. 8, no. 4, pp. 675-682, May 1990.

[15] D. E. N. Davies, "Independent angular steering of each zero of the directional pattern for a linear array," ***IEEE Trans. Antennas Propagat,*** vol. AP-15, pp. 296-298, 1967.

[16] J. Mayhan. "Nulling limitations for a multiple beam antenna," ***IEEE Trans. Antennas Propagat,*** vol. AP-24, pp. 769-779, Nov. 1976.

[17] M. Haardt & Q.Spencer, "Smart Antennas for Wireless Communications beyond the Third Generation", Elsevier Journal of Computer Communications, no.26, pp. 41–45, 2003.

[18] R. Monzingo and T. Miller, *Introduction to Adaptive Arrays*. New York: Wiley, 1980.

[19] R. Shore and H. Steyskal, " Nulling in linear array patterns with minimization of weight perturbations," RADC-TR-82-32, (AD-A118695), Feb. 1982.

[20] H. Steyskal, " Wide-band nulling performance versus number of pattern constraints for an array antenna." *IEEE Trans. Antennas Propagat.*, vol, AP-31, pp. 159-163, Jan. 1983.

[21] R. Shore, " The use of a beam space representation and nonlinear programming in phase-only nulling," RADC-TR-124, (AD-A131365), May 1983.

[22] H. Steyskal, " Simple method for nulling by phase perturbation," *IEEE Trans. Antennas Propagat.*, vol. AP-31, pp. 163-166, Jan.1983.

[23] R. Haupt, "Nulling with limited degrees of freedom," RADC-TR-83-114, (AD-A132276), Apr. 1983.

[24] C. Baired and G. Rassweiler, "Adaptive sidelobe nulling using digitally controlled phase-shifters," IEEE Trans. Antennas Propagat., vol. AP-24, Sept. 1976.

[25] T.S.Rappaport, "Mobile Communication Principles and Practices", Prentice Hall of India, 2000.

[26] W.C.Y.Lee, "Mobile Cellular Telecommunication System," McGraw Hill, New York, 1989.

List of Publications

1. Anisha, R. Khanna , Yugnanda, " Key Research issues of Smart Antennas," Proc. Of National conference in Electronics Circuits and Communication (ECCS-2004), Thapar Institute of Engineering & Technology, Patiala, Sept. 2004.

2. Anisha, R.Khanna, " Implementation of Adaptive Beamforming Algorithms (LMS & SMI) in Antenna Arrays," Proc. of 8th Punjab Science Congress, Punjabi University, Patiala, Feb. 2005.

3. Anisha, R. Khanna, "Independent Angular Steering of each zero of the directional pattern of Linear Array," Proc. of International Conference on Challenges in Networking & future of e-Commerce CNFE'05, APIIT SD, Panipat, April 2005.