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Performance Analysis Of Linearly Constrained Minimum Variance Beamformer

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***Abstract*—Adaptive beamforming is a signal processing method of signal propagation; the aim is to gain the optimum weights of the phase array by some adaptive beamforming algorithms, and finally adjust the main lobe to focus on the arriving direction of the desired signal, and also suppress the interfering signal. By these ways, the system can receive the interesting signal efficiently. In practical application, the speed of convergence, complexity, and robustness are the main factors to be considered when choosing an adaptive beamforming algorithm. This paper focuses on linearly constrained minimum variance (LCMV) adaptive beamforming with the help of MATLAB. In this paper, computer simulation shows the LCMV beamformer performs better result compared to Minimum Variance Distortion-less Response (MVDR) beamformer. The values of SINR has been higher than MVDR are also evaluated in this paper. Actually, here focuses on how interference is cancelling by using LCMV and will also be shown that the LCMV gives much better result than MVDR. MATALB simulation environment is used to analyze the performance of the proposed LCMV beamformer by using LCMV algorithm and related others parameters. LCMV beamformer is capable to reject interferences, provides higher directivity and capable to reduce SLL.**

Keywords—Antenna; Beamformer; MVDR; LCMV

I. INTRODUCTION

Antenna is an essential equipment for wireless communication. At present, smart antenna are widely used in various application like mobile communication, radar, sonar etc. due to their adaptive characteristics. Smart antenna has numerous advantages like higher signal-to- interference ratios, sidelobe canceling or null steering, improved system capacities, higher permissible signal bandwidths, multi path mitigation, enhanced angle-of-arrival estimation and direction finding, instantaneous tracking of moving sources, increased degrees of freedom etc. Smart antenna uses antenna array and beamforming technique to facilitate the above mentioned advantages. Beamforming is a technique that combine the output of the individual antenna elements of the antenna array and steer the main beam to any desired direction and cancel the directional interference. There are several control that can be used to shape the overall radiation pattern of the antenna array. These are-

- The configuration of the overall antenna array
- The relative spacing between elements
- The excitation amplitude of the individual elements
- The excitation phase of the individual elements
- The relative pattern of the individual elements

This thesis is based on ‘’adaptive antenna array processor”. In this thesis, linearly constrained minimum variance (LCMV), Minimum variance distortionless response (MVDR) are proposed and the performance of the proposed antenna has been analyzed in different perspective and also the performance of the LCMV and MVDR are compared to other existing literature to show its superiority.

II. Background and System Model

Minimum variance distortionless response and linearly constrained minimum variance algorithms are discussed in this chapter. LCMV reject the interference, reduce the overall mixture energy, and preserve the target signal. On the other hand, MVDR reduce the interference plus noise energy without distorting the desired signal. Comparison between conventional and adaptive beamforming are also shown.

II.I. Beamforming Types

When the antenna array is in the transmitting mode, beamformer controls the relative phase and amplitude of the signals in the order to create a constructive and destructive interference pattern in the wavefront. When the antenna array is in the receiving mode, information of all elements is added in a such way where the desired radiation pattern is discriminately observed. Beamforming techniques may be divided into to categories. These two beamformer are [1]-

- Conventional (fixed or switched beam) beamformers
- Optimal or adaptive (phased array) beamformer

II.I.I. Conventional Beamforming

The conventional beamformer, sometimes also known as the delay-and-sum beamformer. The delay-and-sum beamformer has no capability to reject interference. The weights of delay-and-sum beamformer are equal in magnitude. The phases are selected to drive the array in a specific direction (φ,θ) which is called look direction. A delay-and-sum beamformer is shown in Fig.1.

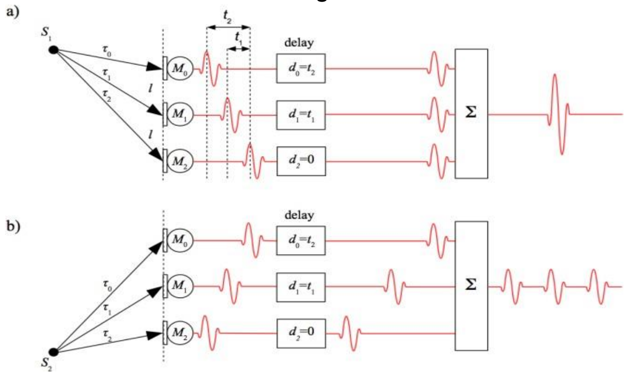

Fig.1: (a) and (b) are delay-and sum beamformer [Google, 13 December, 2020]

If **sd** is the look direction steering vector and **L** is the total number of antenna elements, the array weight is given below [2]-

$$W_c = \frac{1}{L} sd \qquad \textbf{(1)}$$

The output of delay-and-sum beamformer can be obtained by taking the dot product of weight vector **Wc** and steering vector **s** (φ,θ). The output becomes as [2]-

$$Y(\varphi,\theta) = w_c^{H} s(\varphi,\theta) = \frac{1}{L} sd^{H} s(\varphi,\theta) \qquad \textbf{(2)}$$

The behavior of this processor is examined under different conditions. The array with these weights has unity power response in the look direction.

II.II. System model

One of the control parameter that can be used to measure the overall power pattern is geometry structure of the antenna array. The geometry structure of antenna array may be linear, circular, rectangular etc. Different structures of antenna array are shown in this chapter.

A block diagram of a narrowband communication system based adaptive antenna array is shown in Fig.2. In this system, the signals induced on the antenna elements are multiplied by adjustable required complex weights and then the weighted signals are aggregated to produce signal output of the system. The process to assemble the signals from different antenna elements to produce a single output is called beamforming.

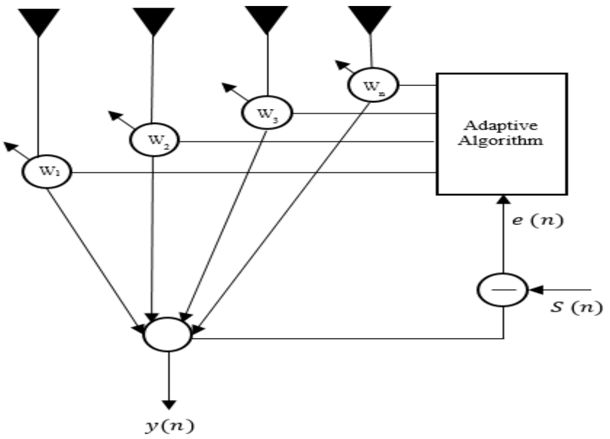

Fig.2: Antenna array model [Google, 13 December, 2020]

Array induced signals, system output and direction of the signal-of-interest are provided to the processor as additional information. The processor computes the complex weights to be used for each channel. Depending on the application, type of antenna elements are chosen and additional information is provided to the processor e.g. a communication system uses antennas as sensors and use some signal properties as additional information. To discriminate the desired signal from the unwanted signal. This type of additional information is used by the array processor.

II.III. Mathematical Model

In mathematical model, by calculating the mathematical equation we are evaluating our expected result by using MATLAB environment. Under these mathematical model, signal model expression and steering model expression are calculated. These are given elaborately in below-

II.III.I. Signal Model

Consider a narrowband beamformer based communication system shown in Fig.2. which consists of an array of L elements. The signal induced on various elements are multiplied by variable complex weights and the weighted signals are aggregated to produce the array output. If **z** (t) indicates the induced signal on the antenna elements and **w** indicates the weight vector, the array system output becomes as [2]-

$$y(t) = \sum_{j=1}^{L} wj * zj \quad (3)$$

Where, * denotes the complex conjugate **z (t)** and **w** are represented in vector notation as,

$$z(t) = [z1(t), z2(t), \ldots\ldots\ldots zL(t)]^T \quad (4)$$

$$w = [w1, w2, \ldots\ldots\ldots wL]^T \quad (5)$$

The output of the antenna array is represented in vector form as [2],

$$y(t) = w^H z(t) \quad \textbf{(6)}$$

where, superscript $(.)^T$ and $(.)^H$ indicate transposition and complex conjugate transposition of a vector or matrix, respectively. The output power of the array at any time t becomes as [2],

$$p(t) = |y(t)|^2 = y(t)\, y^*(t) \quad (7)$$

Putting the value of y(t) from (6), output power of (7) can be expressed as,

$$p(t) = w^H z(t)\, z^H w \quad \textbf{(8)}$$

If the components of **z**(t) can be modeled as zero-mean stationary processes, then for a given **w,** the mean output power of the antenna array can be attained using conditional expectation over **z**(t)[2],

$$p(w) = E[w^H z(t)\, z^H w] = w^H E[z(t)\, z^H] w = w^H Rw \quad (9)$$

Where, E [.] symbolizes expectation operator and **R** represents correlation matrix. **R** is definedas,

$$\mathbf{R} = E[z(\mathbf{t})\, \mathbf{z^H}] \quad (10)$$

The elements of this correlation matrix indicate the correlation between different elements. For instance, **R** jk indicates correlation between the j^{th} and k^{th} element of the array. Consider a environment consist of desired signal source in the presence of unwanted interference and random noise. The random noise consist of both background and electronic noise. Let **zd(t)** indicates the desired signal vector, **zj(t)** indicates the signal vector due to unwanted interference and **n(t)** is the signal vector owing to random noise. In the output the portions due to signal, interference, and random noise are represented by yd(t), yi(t), and yn(t) those are obtained by taking the inner product of the weight vector with wd(t), wi(t), and wn(t) and n(t). yd(t), yi(t), and yn(t) can be expressed as[2]-

$$y_d = w^H z_d(t) \quad (11)$$

$$Y_i = w^H z_i(t) \quad (12)$$

$$y_n = w^H n(t) \quad (13)$$

The correlation matrices for desired signal source, interference signal and random noise s

ignal are $\mathbf{R_d}$ **,** $\mathbf{R_i}$ **,** $\mathbf{R_n}$ respectively, can be defined as,

$$\mathbf{R_d} = E[z_d(\mathbf{t})\, \mathbf{z_d}\, \mathbf{H(t)}] \quad (14)$$

$$\mathbf{R_i} = E[z_i(\mathbf{t})\, \mathbf{z_i}\, \mathbf{H(t)}] \quad (15)$$

$$\mathbf{R_n} = E[z_n(\mathbf{t})\, z_n\, \mathbf{H(t)}] \quad (16)$$

The summation of $\mathbf{R_d}$, $\mathbf{R_i}$, $\mathbf{R_n}$ is represented by **R** which is known as correlation matrices is givenby[2]-

$$R = R_d + R_i + R_n \quad \textbf{(17)}$$

Let $\mathbf{p_d}$, $\mathbf{p_i}$ and $\mathbf{p_n}$ indicate the mean output power owing to desired signal source, unwanted interference signal, and random noise, respectively. According to 9 $\mathbf{p_d}$, $\mathbf{p_i}$ and $\mathbf{p_n}$ becomes as-

$$Pd = w^H R_d\, w \quad (18)$$

$$Pi = w^H R_i\, w \quad (19)$$

$$Pn = w^H R_n\, w \quad (20)$$

Let $\mathbf{p_N}$ indicates the mean output power of the array caused by noise and interference, $\mathbf{p_N}$ is written as-

$$p_N = p_i + p_n \quad (21)$$

Where p_N is the mean noise power at the output. The noise here includes random noise and contributions from all sources except the desired signal. This is also known as noise plus interference. Putting the value of **pi** and **pn** from 18 and 19 and 20,

$$p_N = w^H Ri\, w + w^H Rn\, w = w^H (Ri + Rn)\, w \quad \textbf{(22)}$$

RN is the noise array correlation matrix and given by,

$$R_N = R_i + Rn \quad (23)$$

Then p_N, can be represented in terms of w and R_N as-

$$p_N = w^H R_N\, w \quad (24)$$

The output signal-to-noise ratio (SNR), also known as the signal-to-interference-plus-noise ratio (SNIR), is defined as [2],

$$SNR = \frac{pd}{pN} = w^H W^{-H} (R_d\, Rn^{-1}) ww^{-1} \quad (25)$$

The performance of the system depends on the weights of the array system and the process to determine the weights depends on the application and different types of beamforming techniques. At any instant, the induced signal on the reference element due to k^{th} source becomes as [2]-

$$m_k(t) = e^{j2\pi f t} \quad (26)$$

where, $m_k(t)$ indicates the modulating function in complex form and fo indicates the frequency of the carrier signal. If wavefront reaches on the l^{th} element τ1 (φk,θk) seconds before it reaches at the reference element, the induced signal on the 1^{th} element due to k^{th} source becomes as[2]-

$$m_k(t) = e^{j2\pi f_\circ (t+\tau_1(\varphi_k,\theta_k))} \quad (27)$$

If there are M directional source and $z_l(t)$ denotes the total induced signal due to M directional source on the l^{th} element, then

$$z_l(t) = \sum_{k=1}^{M} m(t) e^{j2\pi f_\circ (t+\tau(\varphi_k,\theta_k))} + n_l(t) \quad (28)$$

where, $n_l(t)$ is random noise component on the l^{th} element and it is to be uncorrelated with directional source e.g.,

$$E[m_k(t) n_l(t)] = 0 \quad (29)$$

II.III.II. Steering Vector Expression

Steering vector is defined as a vector with dimension **L** and it contain the responses of all **L** elements of the array to a narrowband source of unit power. If **sk** indicates the steering vector for the **k^th^** source and it is defined for an array of identical elements by [2]-

$$s_k = [\exp(j2\pi f_\circ (\tau_1(\varphi k, \theta k)) \exp(j2\pi f_\circ (\tau_L(\varphi k, \theta k))]^T \quad (30)$$

$(\tau_1(\varphi k, \theta k)) = 0$ if the reference element is at the origin of the co-ordinate system. The steering vector is related with each directional source as the response of the array is changed with the direction of directional source. Uniqueness of this relation depends on overall array geometry. For an array of identical elements, each component of this vector has unit magnitude. The phase of its **i^{th}** component is equal to the phase difference between signals induced on the **i^{th}** element and the reference element due to the source associated with the steering vector. As each component of this vector represents the phase delay caused by the spatial position of the corresponding element, this vector is also called as space vector. Putting equation 30 in 28, the signal vector expressed as [2]-

$$\mathbf{z(t)} = \sum_{k=1}^{M} m_k s_k + \mathbf{n(t)} \quad (31)$$

Substituting the value of **z(t)** from (31) in (6), it becomes[2]-

$$y(t) = w^H z(t) = \sum_{k=1}^{M} m_k s_k w^H + w^H n(t) \quad (32)$$

The first term of the right side of 32 is due to all desired sources. The second term due to the contribution of noise to the output of the array. The contribution of all desired sources contained in the first term is the weighted sum of, modulating functions of all sources. The output signal of an array in the term of w toward a source in the direction (φ,θ) is represented as-

$$y(\varphi,\theta) = w^H s(\varphi,\theta) \quad (33)$$

R is derived in terms of steering vectors. Putting the signal vector **z(t)** from (30) in the equation of **R** in (10) becomes as-

$$\mathbf{R} = E[(\sum_{k=1}^{M} m_k(t) s_k) + n(t) (\sum_{k=1}^{M} m(t) s_k + n(t))^H] \quad (34)$$

III. Adaptive Antenna Processor

Adaptive beamformers are designed with the aim of detection of noise and intentional destructive interference and then removing them from the desired signal. This is done by placing high attenuation in the direction of the destructive signal in the radiation pattern of antenna arrays without attenuating the signal from a known direction. Minimum variance distortionless response and linearly constrained minimum variance are among such algorithms in wireless communications. Minimum variance distortionless response and linearly constrained minimum variance techniques are discussed in this chapter. LCMV reject the interference, reduce the overall mixture energy, and preserve the target signal. On the other hand, MVDR reduce the interference plus noise energy without distorting the desired signal. Comparison between conventional and adaptive beamforming are also shown. By using matlab performance between the MVDR and LCMV are found in this chapter.

III.I. Theory of MVDR and LCMV Beamformers

Adaptive beamforming is a technique that performs adaptive spatial function in signal processing with an array of transmitter or receiver. The signals are combined in a pattern in which the signal strength are increased to/from a chosen direction. This technique adapts the system parameters in order to maximize the receive signal power, while minimizing noise (such as interference or jamming) [11].

The beamformers used in this study have a uniform linear array of N dipole antennas with $d=\frac{\lambda}{2}$ distance in between where λ is the wavelength of the carrier signal. The beamformer output at time n which is the summation of the weighted received signals by each antenna is given by [3] Eq. (34)

$$y(n) = w^H u(n) \quad (35)$$

where, $u(n) = [u_0(n), u_1(n) \ldots\ldots u_{N-1}(n)]^T$ is the complex signal vector observed at time n and w(n) = $[w_0(n), w_1(n) \ldots\ldots w_{N-1}(n)]^T$ is the complex weights vector of the beamformer. H represents the Hermitian operator.

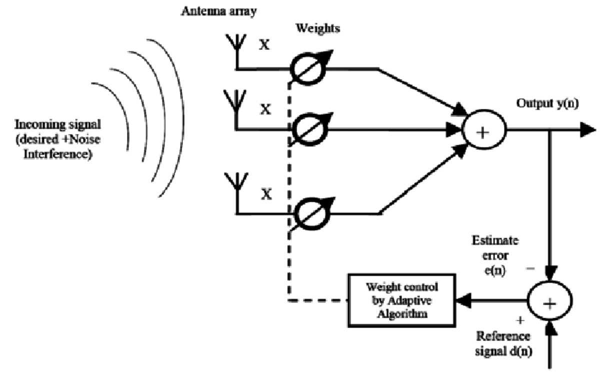

Fig3: Adaptive antenna array beamforming block diagram [Google, 15 December, 2020]

Then the adaptive array factor for the far field will be-

AF(θ) $=\sum_{n=1}^{N} W_n e^{j(n-1)k_d \cos\theta}$ (36)

Where, **k** is the wave number and $K=\frac{2\pi}{\lambda}$,w is the weight of the antenna array, **θ** is the angle of incidence of interference signal, **λ** is the wave length.

The error is taken in to consideration as the difference between the reference signal (desired signal) to that of the array output will be-

e(n) = S(n) – y(n) (37)

III.I.I. Minimum Variance Distortionless Response Technique

MVDR beamformer is designed to cancel the interference and noise signals and to maintain the desired signal in a specific direction. For this purpose, the output power is minimized subject to the constraint that the desired signal level be 1 in the desired direction which could be any direction, hence distortionless. It means that the antenna array gain does not change by its aperture direction. Equation 35 shows the optimization rule and the constraint [3]-

arg $\min E\{|w^H u(n)|^2\}$ s.t. $w^H s(\varphi) = 1$ (38)

The steering vector s(φ) is shown in Eqs. (35) and (36) where φ is the electrical angle equivalent of the physical angle of the input signal, θ, and d is the distance between antenna array elements.

$s(\varphi) = \{1\ e^{-j\varphi} \ldots\ldots\ldots\ldots\ldots e^{-(N-1)\varphi}\}^T$ **(39)**

$\varphi = \frac{2\pi}{\lambda}.d.\sin(\theta)$

with, Lagrange multiplier method the weights vector is calculated as (39)

$$W_{MVDR} = \frac{S^{-1}s(\varphi)}{s^H S^{-1}s(\varphi)}$$

where, S represents the covariance matrix of the environment which is estimated from the received signals of the antennas. In the estimation of the covariance matrix, the input data must be free from the desired signal. As the focus of this article is on hardware implementations the covariance matrix is considered to include only interference and noise signals.

iii.i.ii Linearly Constrained Minimum Variance Technique

In the LCMV beamformer, the aim is to preserve the desired signal in multiple angles, mainly two, in addition to attenuating the noise and interference signals. This resolves the self-nulling problem of MVDR. The constraints are represented by a N x Mc matrix, C, where Mc is the number of the preserved angles and the columns of the matrix are the steering vectors in those directions. g^H is a vector with size 1 x Mc and all its elements are one. The optimization equation is defined [3] as (36),

arg $\min E\{|w^H u(n)|^2\}$ s.t. $w^H C = g^H$ (40)

Like MVDR, the LCMV weights vector is obtained from the Lagrange multiplier as (37)

$w^H_{LCMV} = g^H[C^H S^{-1} C]^{-1} C^H S^{-1}$ (41)

III.II Performance Analysis

The performance of the proposed LCMV and MVDR algorithm system is evaluated in this section using MATLAB environment. To analyze the performance of the two algorithm different equations are used. By using these equations we find out our desired outcome. The signal frequency and propagation speed are considered 1.2 GHz and 3 x 10^8 m/s respectively. The impact on the performance due to variation of different parameters of the beamformer is also analyzed.

III.II.I. Performance of MVDR

By using different parameters different curve pattern will be found out in this section. These are shown below-

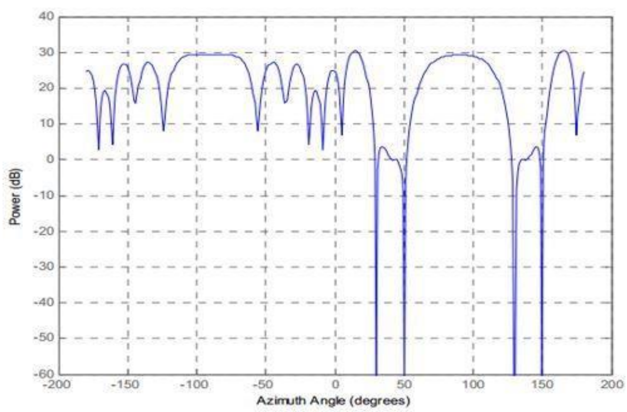

Fig.4. MVDR power vs azimuth angle curve

Here, in Figure 4 we see that the power in decibel versus azimuth angle curve in degree is shown. At angle -190° to -125° signal is attenuated. And at angle -125° to -49° gives the desired output power. Similarly, at angle -50° to +50° signal is attenuated and at angle +50° to 130° gives the desired output power.

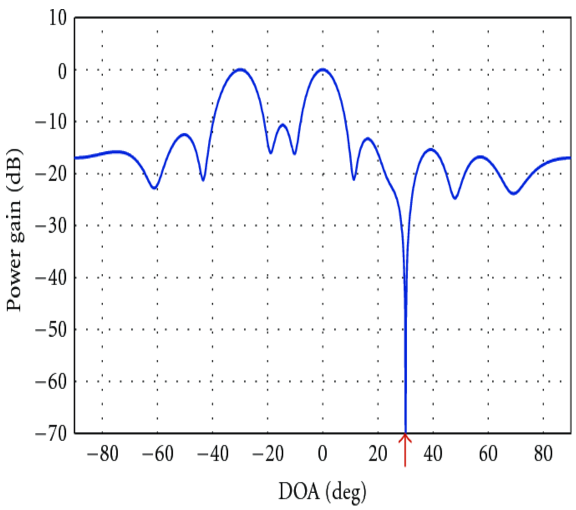

Fig.5. MVDR power gain vs Direction of Arrival (DOA) curve

Here, in Figure 5 we show the power gain in decibel versus direction of arrival curve in degree. At angle 30° power gain collapse. At that point DOA occurred.

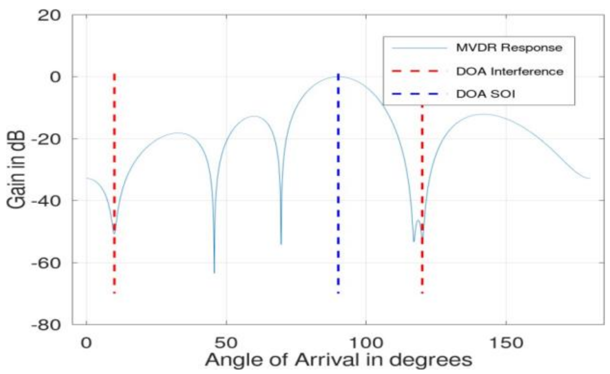

Fig.6. MVDR response with DOA interference and SOI

Here, in Figure 6 gain in decibel versus angle of arrival curve in degree is shown. Actually conventional beamforming is incapable to cancel any interference but MVDR beamformer has the capability to cancel interference. And the expected MATLAB output is shown in figure.

Here, in Figure 7 normalized power in decibel versus azimuth angle curve in degree shown. Here, we see that compare the two signal values but both the signal gives the same output at 30° and 45°.

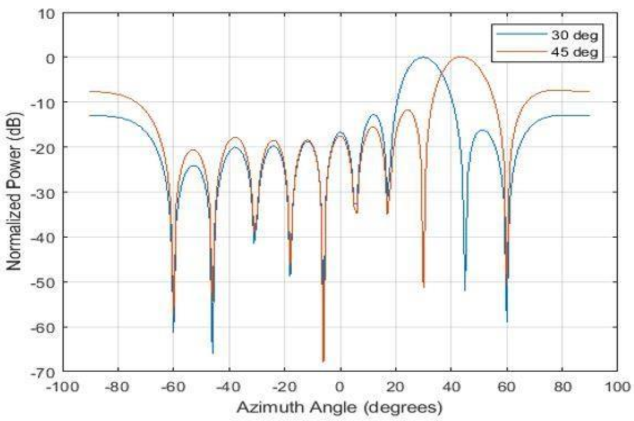

Fig.7. MVDR power curve for different degrees

III.II.II Performance of LCMV

By using different parameters different curve pattern will be found out in this section. These are shown below-

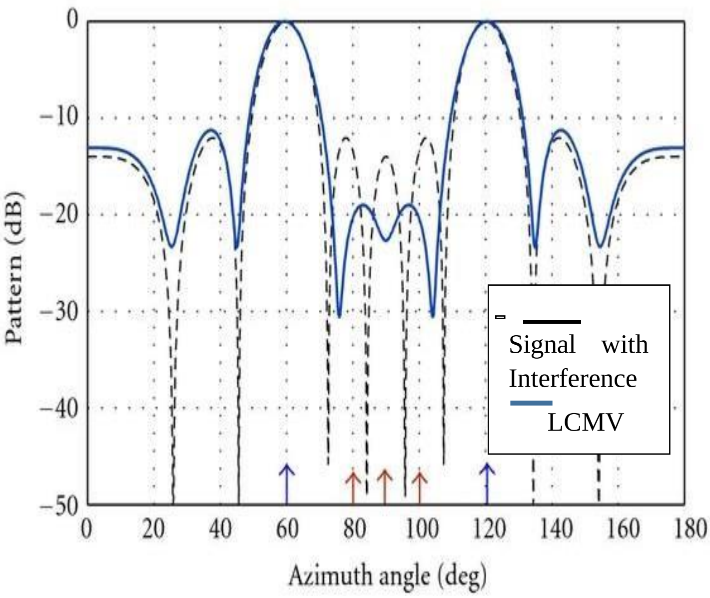

Fig.8. LCMV power pattern vs azimuth angle

Here, in Figure 8 power pattern in decibel versus azimuth angle curve in degree is shown. LCMV is an adaptive beamformer. And it gives the best interference rejection in a signal. And also gives the desired MATLAB output. From figure we see that at angle 70° to 110° signals are attenuated for the present of interference in the signal. By using the LCMV the attenuation are cancelled 70°to 110°.

Here, in Figure 9 normalized power in decibel versus azimuth angle curve in degree is shown. Here also, normally shown the LCMV power pattern curved which gradually varied at angle

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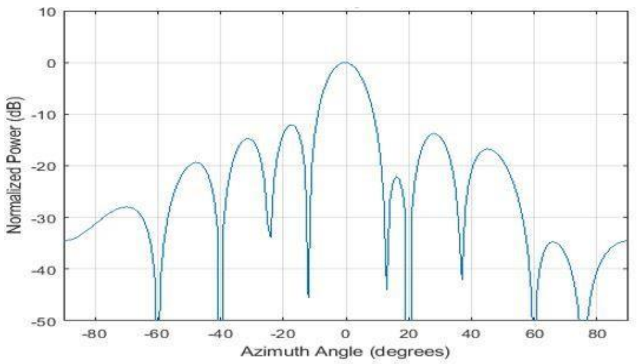

Fig.9. LCMV power vs azimuth angle curve

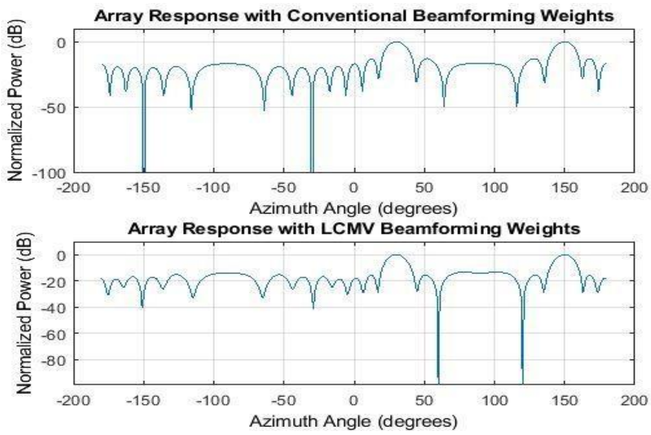

Fig.11.comparison curve between conventional beamforming and adaptive beamforming

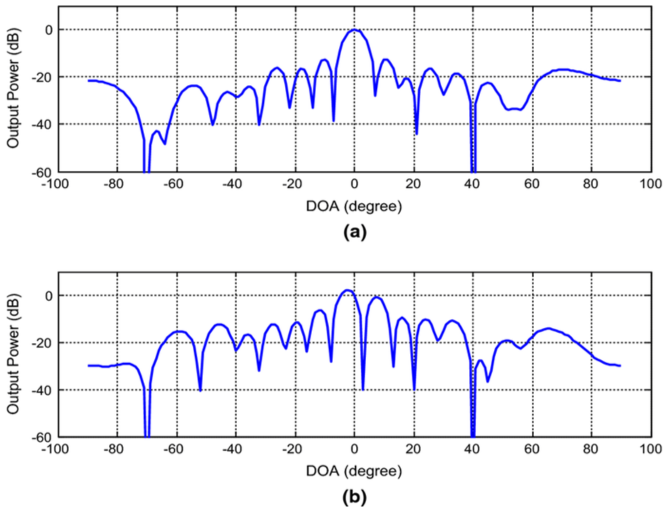

Fig.10. LCMV power vs DOA curve (a) without LCMV and (b) with LCMV

Here, in Figure 10 output power in decibel versus DOA curve in degree is shown. (a) is the without LCMV signal and (b) with LCMV signal. Here, we clearly realize the difference in signal pattern by using with and without LCMV. Where in (a) signals are attenuated more where as the same signal cancel attenuation by the using of LCMV. And the values of output power are also increasedat (b).

III.II.III. Comparative Study between LCMV and MVDR

MVDR and LCMV curve are given below-

Here, in figure 11 normalized power in decibel versus azimuth angle curve in degree is shown and Also in this figure compared the signal power by using Conventional beamforming and LCMV beamforming. Conventional beamforming is unable to cancel the interferences on the other hand LCMV has the capability to reject interferences and we can easily realized that from figure 11. For the same angle LCMV gives the much better output than conventional beamforming.

Here, in Figure 12 power in decibel versus azimuth angle curve is shown. Here, also compared the result between LCMV and MVDR. MVDR is an conventional beamforming and LCMV is an adaptive beamforming. We know that, LCMV is capable of cancelling interferences. Conventional beamforming is unable to cancelling interferences but MVDR has the capacity to cancelling interferences. But The LCMV is much more capable than MVDR to cancelling interferences and also it is clearly depicted from figure 12 at angle 0° the value of LCMV 19 dB and MVDR is 9 dB. LCMV signal is less attenuated than MVDR signal. And the values of LCMV is comparatively higher than MVDR.

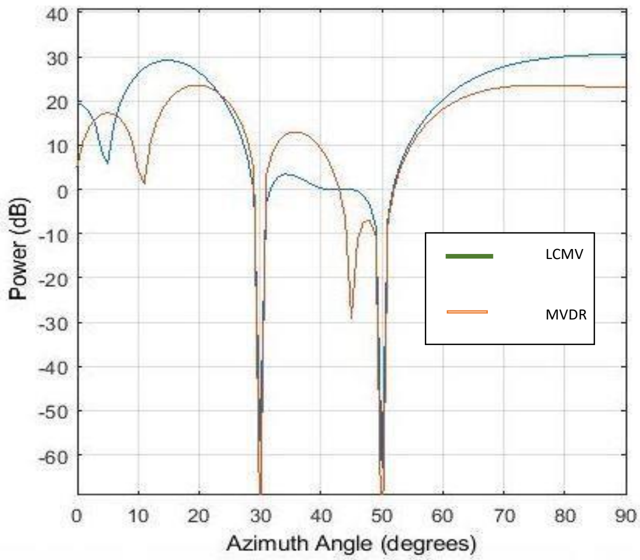

Fig.12. Comparison curve between MVDR and LCMV

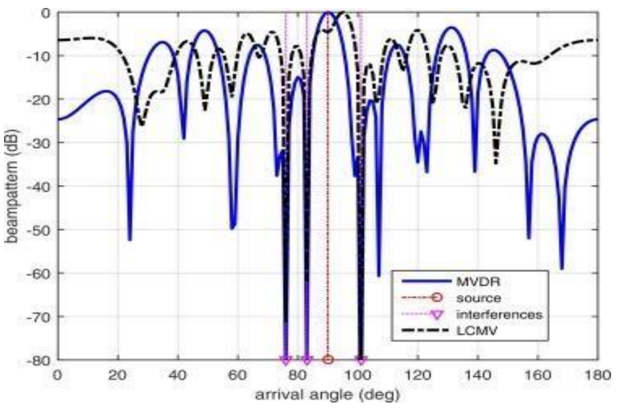

Fig.13. Comparison curve between LCMV and MVDR with source and interferences

From, Figure 13 we see that LCMV gives much better result than MVDR. As above, again and again we say that LCMV is capable of cancelling interferences than conventional beamforming so in Figure 13 it is clearly depicted that LCMV is much more capable than MVDR to reject interferences. So we can easily say that, adaptive beamforming is comparatively gives much betterresult than conventional beamforming.

In section ***III.II.I.*** and ***III.II.II.*** the MATLAB output are individually shown for MVDR and LCMV beamforming. And in section ***i*** compared the MVDR and LCMV ′ s parameters values for finding which one gives the better performance. After evaluating these MVDR and LCMV values individually and together we can easily say that LCMV beamformer gives comparatively much better result. LCMV beamformer has comparatively much better strength for nulling a side band, reducing noise and interferences. LCMV beamformer increases the gain. Higher gain means that signal is much stable. And avoiding the effect of fading, noise and interferences are higher. And also LCMV increases SINR values means that the system is ready to face any kind of interferences without losing any information strength. As LCMV is a part of adaptive beamforming so the adaptive beamforming gives much better result than conventional beamforming.

IV. Conclusion

In smart antenna applications, the adaptive beamforming technique has been used to reject interfering signals (placing nulls) and produce or steer a strong beam toward the target signal according to the measured weight vectors. MVDR beamforming has been able of determining the weight vectors for beam steering; however, its nulling level on the interference sources remains unsatisfactory. If any mismatch occurred within direction of desired incoming signal and the main beam steering direction then MVDR beamformer assumes the original signal as interfering signal and strongly dissipated SOI. Beamforming can be considered as an optimization problem, such that optimal weight vector should be calculated through computation. On the other hand, the concept of “beamforming” refers to multichannel signal processing techniques that enhance the acoustic signals coming from a particular a priori known position, while reducing the signals coming from other directions. A number of beamforming techniques exist, a review of which may be found in [14]. In this thesis paper, we introduce LCMV beamformers, which has been widely used in acoustic array processing. The class of the LCMV beamformers is general enough to form a common framework to design beamforming algorithms for various physical setups.

Section III.I.II. defines the LCMV beamforming principle. Section III.II.II. shows the performance of LCMV.

We have been also done comparison between LCMV and MVDR in section iii.ii.iii to show which one gives comparatively better result.

The proposed LCMV has the following characteristics-

- Increased SINR values
- Able to minimize the SLL
- Provide better performance to reject the directional interference
- Capable of reduce steering angle disparity

V. Future Work

There are some scopes to continue further research on the thesis work presented in this thesis. Some of the scopes are listed below-

- To increase the wideband or reduce the wideband in the wireless communication can be applied.
- Adaptive beamforming is to use a finite set of fixed-antenna patterns, which will generate a set of beams matched to the long term transmit covariance matrices of different parts of the coverage area .
- The adaptation is typically done over long term Channel State Information (CSI), the required amount of feedback signaling is low or even none in case uplink received signals are used to determine which beam is the best.
- Broadband beamforming can be applied to the proposed adaptive beamforming.
- Conventional beamforming is also applied for the proposed work.

REFERENCES

[1] L.C. Godara, *Smart antennas.* CRC press, 2004

[2] C.A. Balanis, *Antenna theory analysis and design.* John Wiley and Sons Inc, 2005.

[3] Y. Huang, M. Zhou, and S.A. Vorobyov, "New design on MVDR roubst adaptive beamforming based on optimal steering vector estimation," *IEEE Transactions on Signal Processing,* vol. 67, no. 14, pp. 3624-3638,2019.

[4] W.L. Stutzman and G.A. Thiele, *Antenna Theory and Design, Second Edition.* John Wiley and Sons, Jan. 1998.

[5] J. G. Proakis, Digital Communications, Fourth Edition. New York: McGraw-Hill.

[6] G. Maral and M. Bousquet, Satellite Communications Systems: Systems, Techniques and Technology. John Wiley and Sons, 2000.

[7] B. Pattan, (2000), Robust Modulation Method and Smart Antennas in Wireless Communication. Englewood Cliffs: NJ: Prentice-Hall, 2000.

[8] J. Litva, and T. Lo, (1996), Digital Beamforming in Wireless Communication.Boston: Artech House, 1996.

[9] N. Fourikis, (1996), *Phased Array-Based Systems and Applications*. New York:Wiley, 1996.

[10] A. Chkeif, K. Abed- Meraim, G. Kawas-Kaleh, and Y. Hua, (2000), Spatial- temporal blind adaptive multiuser detection*. IEEE Transactions on Communication,*48(2000), 729-732.

[11] K.B. Yu, (1994), Adaptive beamforming for satellite communication with selective earth coverage and jammer nulling capability. *IEEE Transactions on Signal Processing,* 44(1994), 3162-3166.

[12] T. Gebauer, and G.H. Gockler, (1995), Channel individual adaptive beamforming for mobile satellite communications. *IEEE Journal On Selected Areas in Communications,* 13(1995), 439-448.

[13] A.R. Horton, and K. Abend, (1993), Adaptive array antenna for satellite cellular and direct broadcast communications. *In proceedings of the 3rd International satellite Conference,* Pasadena, CA, 1993, 47-52.

[14] J. S. Goldstein, and I. S. Reed, (1997), performance measures for optimal constrained beamformers*. IEEE Transactions On Antenna and Propagation,* 45(1997),11-13.

[15] L. C. Godara, (1997), Applications of antenna arrays to mobile communications, Part I: Performance improvement, feasibility, and system considerations. *Proceedings of the IEEE,* 85(1997), 1031-1060.

[16] L. C. Godara, (1997), Applications of antenna arrays to mobile communications, Part II: Beamforming and directional-of-arrival considerations. *Proceedings of the IEEE*, 85(1997), 1195-1245.

[17] W. Li, X. Mao, Z. Zhai, and Y. Li," High performance robust adaptive beamforming in the presence of array imperfections*," International Journal of Antennas and Propagation*, vol.2016, 2016.

[18] P. S. Diniz, E.A. Da Silva, and S.I. Netto, *Digital signal processing system analysis and design.* Cambridge University Press, 2010.

[19] F. Shen, F. Chen, and J. Song, "Robust adaptive beamforming based on steering vector estimation and covariance matrix reconstruction," *IEEE Communications Letters,* vol.19, no. 9,pp. 1636-1639,2015.

[20] M. Al- Sadoon, R.A. Abd-Alhameed, I. Elfergani, J. Noras, J. Rodriguez, and S. Jones, " Weight optimization for adaptive antenna array using LMS and SMI algorithm," *WSEAS Transactions on Communications*, vol. 15, pp. 206-214, 2016.

[21] M. F. Reza and M.S. Hossain," Robust concentric antenna array with variable loading technique in the presence of look direction disparity," *Progress in Electromagnetics Research,* vol. 57, pp. 35-43, 2017.

[22] J. Makhoul, "Linear prediction: A tutorial review," *Proceedings of the IEEE,* vol. 63, no. 4, pp. 561-580, 1975.