

Avoiding Self Nulling by Using Linear Constraint Minimum Variance Beamforming in Smart Antenna

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Abstract: The beam forming technique is important in smart antenna systems to enhance the data rates, null steering and coverage. This study presents two methods of beamforming algorithm; Minimum Variance Distortion less Response (MVDR) and Linear Constraint Minimum Variance (LCMV). MVDR and LCMV techniques form radiation beams based on the received weight vector of the desired signal. The LCMV technique is found to be efficient than the MVDR in self-null even if the interference signal is closer from the desired signal. Simulation has been carried out to validate these two techniques. The four elements of the linear array smart antenna are used in our simulation program with the operation frequency around 2.3 GHz, noise power 0.5dB and the spacing between elements is 0.5λ . The result of the simulation reveals that both the modes are capable of providing high output power; however they need the direction of all the incoming sources, which is practically difficult to obtain. Nevertheless the MVDR beam forming minimizes the multi-path fading problem, by adding the multi-path signal, which increases the strength of the desired signal and nullifies the interference.

Keywords: Beam forming, LCMV, MVDR

INTRODUCTION

In the past two decades the number of mobile users is increasing day by day. However, the increasing demands for mobile communication services are supported only with a limited radio-frequency bandwidth. This scenario has motivated the introduction of antenna array assisted beam forming techniques (Blogh and Hanzo, 2002). The beam forming techniques are capable of creating an angularly selective transmitter/receiver beam, which can potentially separate signals transmitted on the same carrier frequency but arriving from different angles. Generally the beam forming techniques follow the following procedures:

Direction of Arrival (DOA) estimation and Beam forming depends on the finest assessment of DOA (Van Veen and Buckley, 1988).

Beam forming is a general signal processing technique that moderates the directionality of the reception or transmission of a signal on a transducer array by using adaptive or fixed receive/transmit beam patterns. The beam patterns are generated by modifying the complex weights of the antenna elements in order to make the beam to be directed in the desired direction

(Compton, 1988). The information received from different sensors has to be combined in order to perfectly observe the expected pattern of radiation. Therefore the Receive Beam forming maximizes the sensitivity in the direction of desired user instead of the interferences. During the transmitting process the beam former controls the phase and relative amplitude of the signal at each transmitter and produces a high directional beam in the direction of desired user and nullifies in the direction of interferences. This will increase the SINR of the desired user and reduces the wastage of transmitted power in the unwanted direction. The reception beam forming is independently achieved at each receiver, however in the transmit beam forming, the transmitter has to consider the all receivers to optimize the beam former output (Balanis and Ioannides, 2007; Dahrouj and Wei, 2010) the beam forming techniques are divided in two categories:

Conventional beam forming, which uses a fixed set of weight to get a fixed beam pattern.

Adaptive beam forming uses a set of weight, which is controlled by the properties of received signals. The algorithms are used to vary the beam patterns based on the changes in the environment. This is achieved by modifying the amplitude and phase of weights,

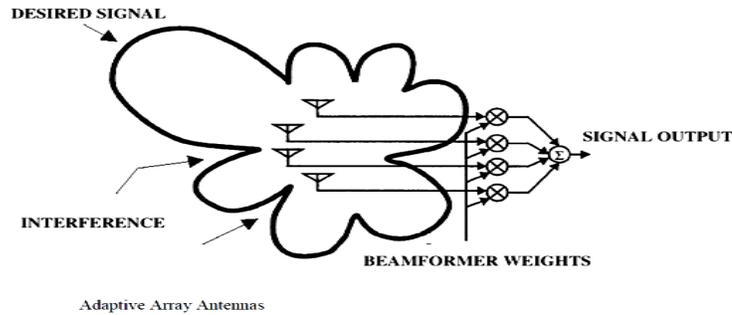


Fig. 1: Beam forming (Balanis and Ioannides, 2007)

direction of main beam, nulls, the width of beam and the side lobe level to optimize the array performance for individual application (Zheng, 2008).

The benefits of beam forming antenna are as follows:

- Increasing the SINR will reduce the frequency reuse distance, which in turn will increase the capacity. Emerging Broadband Wireless systems, which are based on IEEE 802:16m or 3GPP LTE-A, will reclaim the spectrum in all the cells (reuse factor = 1) (Wimax forum, 2010, <http://www.wimaxforum.org/>; LTE forum, 2010 <http://www.alcatellucent.com/>). Assists the ensuing generation wireless system to attain elevated recycle feature.
- The stronger SINR enables the use of higher orders of modulation, such as 64 QAM. This gives higher data rates.
- Beam forming, will increase of the range of Base Station (BS) coverage as the BS will be able to focus its energy towards the intended users instead of directing and wasting it in other unnecessary directions. Thus fewer base stations are required, which gives potentially more cost-efficient deployment.
- Beam forming minimizes multi-path propagation inform the mobile radio environments by constructively including the multi-path signal to increase the strength of the desired signal.

The linearly constrained minimum variance (LCMV) beam former will preferably refuse the undesired signal and reduces the ambient noise power (Compton, 1988). The LCMV is a simplification of the MVDR and generally aims at reducing the beam former's output power and satisfies the multiple constraints such as, rejecting the interference and passing the undistorted desired signal. Of late (Souden *et al.*, 2010; Emanuël *et al.*, 2012) have been proposed another beam former that consists of a weighted sum of the LCMV and a matched filter (i.e., an MVDR that reduces ambient noise only). In order to prevent the signal from self-nulling, we can use an LCMV beam former, which allows us to include multiple constraints

along the target direction (steering vector). It prevents the target signal from being suppressed, when it arrives at a slightly different angle from the desired direction. In this study we have presented two methods of beam former design such as, Minimum Variance Distortionless Response (MVDR) and Linear Constraint Minimum Variance (LCMV).

BASICS OF BEAM-FORMING

Beam forming is an advanced signal processing technique, when this technique is employed with an array of transmitters or receivers it will control the directionality or sensitivity of a specific radiation pattern. This method creates the radiation pattern of the antenna array by adding the phases of the signals in the desired direction and by nullifying the pattern in the unwanted direction. Generally the inter-element phase adjusts the amplitudes in order to optimize the received signal. The Fig. 1 illustrates a standard tool for analyzing the functioning of a beam former (Susmita, 2009).

In Fig. 1 the outputs of the individual sensors are linearly combined after being scaled with the corresponding weights. This optimizes the antenna array to have maximum gain in the direction of desired signal and nulls in the direction of interferers. For beam former the output at any time n , $y(n)$ is given by a linear combination of the data at M antennas, with $x(n)$ being the input vector and $w(n)$ being the weight vector (Ali *et al.*, 2011):

$$y(n) = w^H(n) * x(n) \tag{1}$$

Weight vector $W(n)$ can be define as:

$$w(n) = \sum_{n=0}^{M-1} w_n \tag{2}$$

And

$$x(n) = \sum_{n=0}^{M-1} X_n \tag{3}$$

For any algorithm that evades matrix inverse operation and uses the immediate gradient vector $\nabla J(n)$ for weight vector up gradation the weight vector at time $n + 1$ can be written as:

$$W(n+1) = W(n) + \frac{1}{2} \mu [\nabla J(n)] \tag{4}$$

where, μ is the step size parameter, which controls the speed of convergence and it lies between 0 and 1. The minimum values of μ guides to the sluggish concurrence and high-quality estimation of the cost function; comparatively the huge values of μ might direct to a rapid union however the constancy over a least value might vanish:

$$0 < \mu < \frac{1}{\lambda} \tag{5}$$

An exact calculation of instantaneous gradient vector $\nabla J(n)$ is not possible as prior information of covariance matrix R and cross-correlation vector p is needed. So an instantaneous estimate of gradient vector:

$$\nabla J(n) = -2p(n) + 2R(n)W(n) \tag{6}$$

$$R(n) = X(n)X^H(n) \tag{7}$$

And

$$P(n) = d^*(n)X(n) \tag{8}$$

By putting values from (6, 7 and 8) in (4) the weight vector is found:

$$\left. \begin{aligned} W(n+1) &= W(n) + \mu [p(n) - R(n)W(n)] \\ &= W(n) + \mu X(n) [d^*(n) - X(n)W(n)] \\ &= W(n) + \mu X e^*(n) \end{aligned} \right\} \tag{9}$$

The desired signal can be define by three equations below:

$$y(n) = w^H(n)x(n)$$

$$e(n) = d(n) - y(n)$$

$$W(n+1) = W(n) + \mu X(n)e^*(n)$$

A lot of algorithms have been introduced to design an adaptive beam former. Generally the adaptive beam formers are based on knowledge of the retort of the preferred array; in this case, the output of adaptive beam former becomes very sensitive to any disparity between the modeled and actual desired array responses used in the algorithm. The following sections discuss

the two types of beam formers such as the Linearly Constrained Minimum Variance beam former (LCMV) and the Minimum Variance Distortionless Response beam former (MVDR).

PROPOSED METHODS

Minimum Variance Distortionless Response beam former (MVDR): When beam former has constant response in the direction of useful signal, the LCMV algorithm turns out to be MVDR algorithm. The MVDR algorithm is capable of suppressing the disturbances as much as possible, we do not have to know the direction of disturbance or the strength of the useful signal and white noise, however we need only the direction of useful signal and minimize the output power subject to a unity gain constraint in the direction of desired signal. The array output is:

$$y = w^H x$$

The output power is:

$$p = \{E[y]^2\} = E\{w^H x x^H w\} = w^H E\{x x^H\} w = w^H R \tag{10}$$

where, R covariance matrix should be (M, I) for received signal x , H hermitation transpose

$$x = \begin{bmatrix} x_1 \\ x_2 \\ \cdot \\ \cdot \\ \cdot \\ x_k \end{bmatrix}$$

K number of signals.

The optimum weights are chosen to minimize the array output power P_{MVDR} while maintaining unity gain in a look direction $\alpha(\theta)$ which is the steering vector of the desired signal. The MVDR adaptive algorithm can be written:

$$\min_w \{w^H R w\} \text{ subject to } w^H a(\theta) = 1 \tag{11}$$

Steering vector $\alpha(\theta)$ is:

$$a(\theta) = \begin{bmatrix} 1 \\ \exp\left\{j \frac{2\pi}{\lambda} (\sin \theta_i) d\right\} \\ \exp\left\{j \frac{2\pi}{\lambda} (\sin \theta_i) (m-1) d\right\} \end{bmatrix} \tag{12}$$

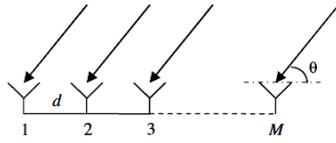


Fig. 2: Linear array incident wave

d the space between elements of antenna, θ_i desired angle, M number of element as shown in Fig. 2.

The MVDR beam former does not require the knowledge of the directions of the interferences for weight vector calculation. It requires only the direction of the desired signal (Compton, 1988). Then the optimization weight vectors can be acquired by the formula below (Gui, 2007):

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

That mean we will get four weights for 4-elements:

$$w_{MVDR} = \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ w_4 \end{bmatrix}$$

Thus, the beam former weights are chosen by maximum value in order to select the element and minimum mean value of output power, based on the number of users inside the coverage, while maintaining unity response in the desired direction. Nevertheless the restraint makes sure that the signal passes through the beam former undistorted. Consequently, the output

signal power is similar to the look-direction source power. Later the total noise such as the interferences and uncorrelated noise is reduced by the minimization process. It is noteworthy that the minimization of total output noise, while constantly maintain the output signal, is same as maximizing the output SINR. However the for the optimal beam former to perform as described above and to maximize the SINR by cancelling interferences, the number of interferences must be less than or equal to $M-2$, because an array with M elements has $M-1$ degrees of freedom and has been utilized by the constraint in the look direction. As the MVDR beam former maximizes the sensitivity only in one direction, this beam former is not suitable for multipath environment, where the desired signal gets spread in all the directions. The multipath occurs in the Non-Line-of-Sight (NLOS) environments such as, populated urban area, where there are many scatterers close to the users and the base station. Thus, the MVDR nullifies the desired signal that comes from different directions, due to multipath fading and that are not suitable for such environment. Thus it can be implemented for rural environment (Compton, 1988).power spectrum in dB and angle in degree of beam forming by using MVDR as shown in Fig. 3.

Liner Convenience Minimum Variance LCMV Beam former:

This kind of beam former restricts the retort of the beam former, so that the signals from a direction of interest are passed with a given gain and phase. The beam former weights are calculated depending on a constraint matrix, C and presumed array response, f ; whereas the constraint matrix, C , is calculated using modeled synthetics with a hyperbolic

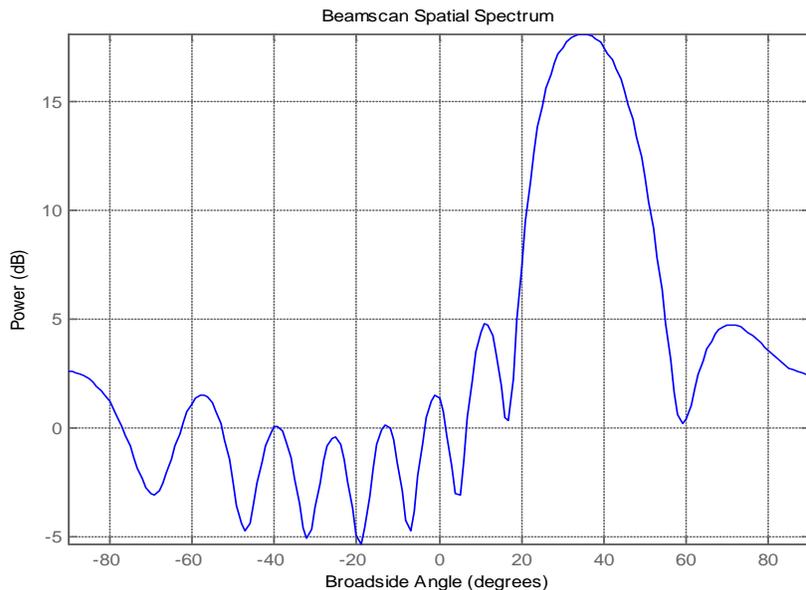


Fig. 3: Power spectrum of beam forming

event (signal) and a linear one (noise) is made redundant with the arrivals shifted with a known time interval (Panea *et al.*, 2010).

LCMV criterion minimizes the output of the beam former based on the constraint of the fixed gains (Lei *et al.*, 2011). This criterion minimizes the output power of the beam former under the constraint of fixed gains in some given values of DOA. So the array is set to receive from the desired user, while minimizing the arrival of interference from the other directions. This criterion is expressed by:

$$W_K = \arg \min \left\{ W_K^H R W_K \right\} \left| C_K^H W_K = f_K \right. \quad (14)$$

where,

- C_K = The matrix of const for the K_{th} user and
- f_K = The response vector for the K_{th} user (Danilo and Charles, 2002).

Of late, the LCMV beam former is used to prevent the null-steering, which allows us to put multiple constraints along the target direction (steering vector). It reduces the possibility of the target signal getting suppressed, when it arrives at a slightly different angle from the desired direction

The LCMV depends on several constraints. In order to specify a constraint, we have to add corresponding entries in the constraint matrices, constraint and the desired response vector and desired response. Each column in constraint is a set of weights, which we can apply to the array and the corresponding entry in the desired response is the response that we want to achieve, when the weights are applied. For example, to avoid self nullifying, we might add the following constraints to the beam former:

- Preserve the incoming signal from the expected direction (θ degrees in azimuth).
- To avoid self nullifying, ensure that the response of the beam former does not decline at $\pm 2^\circ$ of the expected direction.

SIMULATION

This study has carried out a simulation for a 4-element uniform linear array (ULA). The interelement spacing between elements is $[0.5\lambda]$ and 4 elements. We have generated $x(t)$ by using time of sample and carrier frequency 2.3 GHz. The antenna has received these signals by each elements array. $x(t)$ Content from the interference signal and desired signal:

$$x(t) = s(t) + n(t) \quad (15)$$

where, $s(t)$ desired signal, $n(t)$ interference signal. The received signal often includes some thermal noise ($r_{X_{signal}}$). We have assumed that the noise power is 0.5 watts, which corresponds to a 3 dB Signal-to-Noise Ratio (SNR) at each antenna element. From the received signal, we have applied MVDR and LCMV to calculate the weight. These two algorithms depends on the steering vector and covariance matrix to get the optimum weight, interference (null) and the direction of desired signal (main lobe).

Assume that the signal arrives at the array from 10° in azimuth and 0° in elevation and interference signals arriving from 40° and 70° in azimuth. The interference amplitudes are much higher than the desired signal. The SNR value will be 50dB at each antenna.

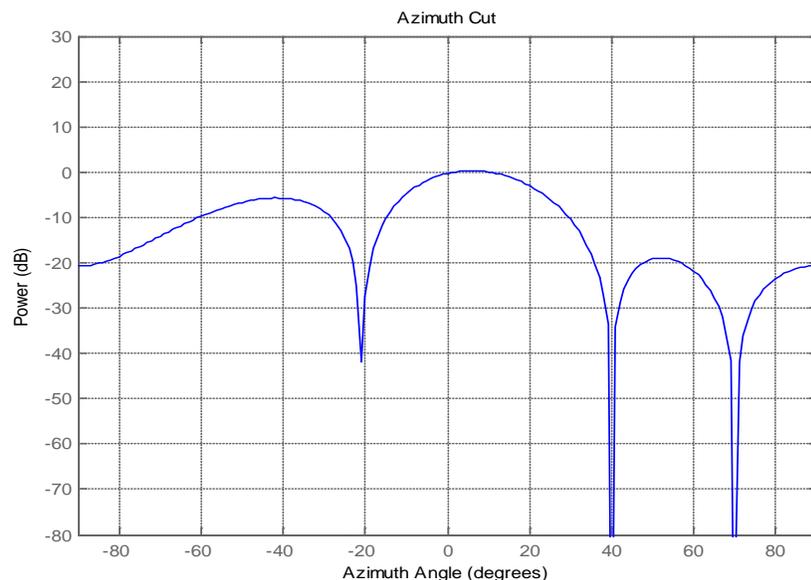
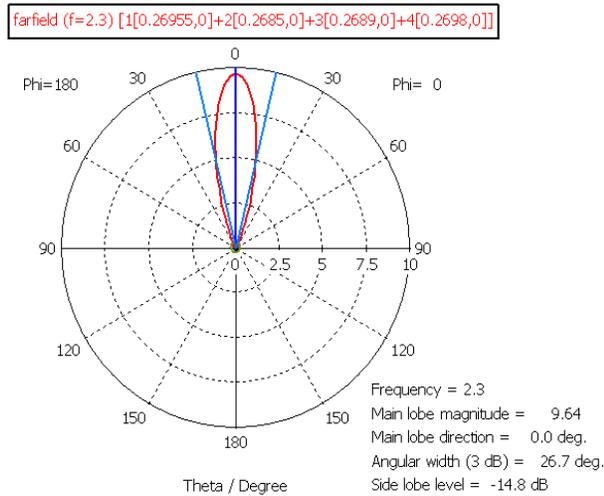
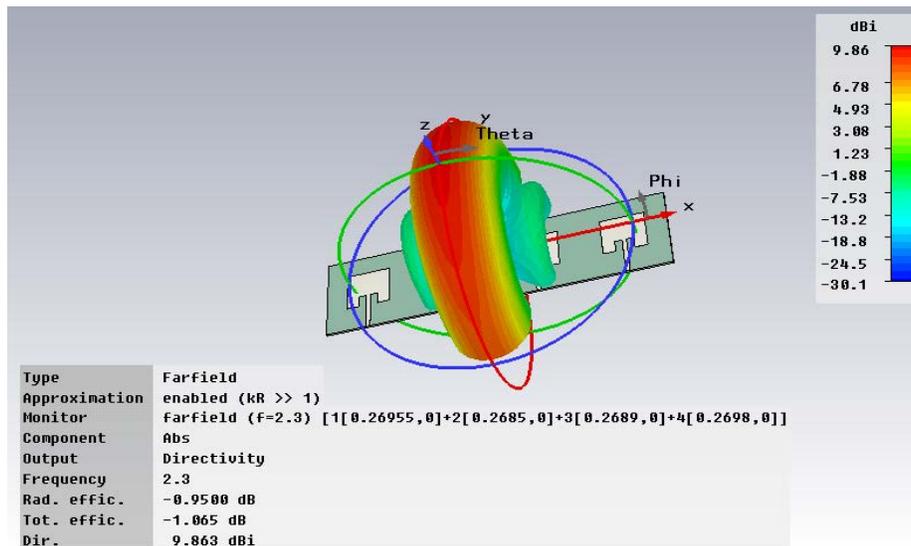


Fig. 4: MVDR beam forming



(A)



(B)

Fig. 5: (A, B) main lobe of MVDR

MVDR algorithm: The MVDR beam former preserves the signal arriving along a desired direction and suppresses the signals coming from other directions. In this case, the desired signal is at 10° in azimuth. We have applied the MVDR beam former to the received signal. The weights are calculated using Eq. (13) to produce a unity response in the direction of desired user ($\varphi = 0^\circ$) and null in the direction of interferences (40° , 70°). At -20° we have got the self-null. The Fig. 4 shows the MVDR beam forming respectively. The main lobe magnitude 9.64 dB as shown three dimension in Fig. 5A and B depend on the values of weight vector for each element ($0.2526-0.0941i$, $0.2292-0.1399i$, $0.2295+0.1403i$, $0.2529+0.0940i$).

LCMV algorithm: A multipath setting is employed in this simulation. Due to the fading of multipath a desired source is arriving from direct path $\varphi = 10^\circ$ with SNR = 50 dB. The weights are calculated using (14) to produce the main beam in the direction ($\varphi = 0$ respectively) and null in the direction of interferences (70°). However, at 40° the interference will appear flat and will not be null. The Fig. 6 shows the power response and the null. The main lobe magnitude is 7.3 as shown in Fig. 7A and B to plot three dimension for LCMV beam forming respectively depend on weight for each elements ($0.2050+2.0098i$, $5.5739+2.4055i$, $5.5755 - 2.4027i$, $0.2061 - 2.0097i$)

The effect of constraints can be better seen when comparing the response patterns of LCMV and the

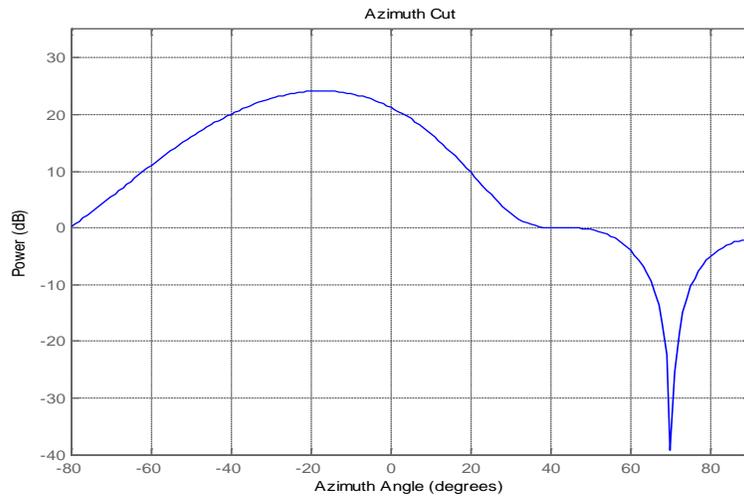
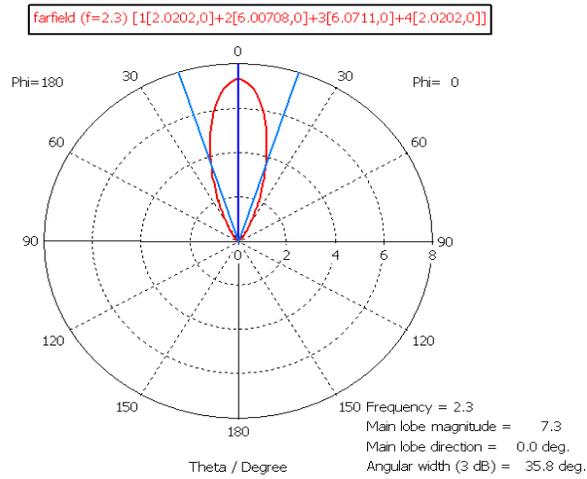
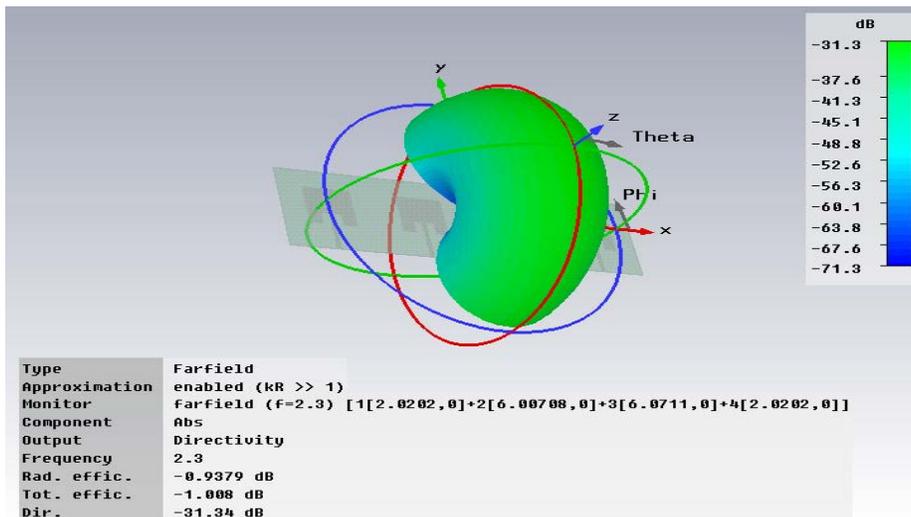


Fig. 6: LCMV beam forming power response



(A)



(B)

Fig. 7: (A, B) main lobe for LCMV beam forming

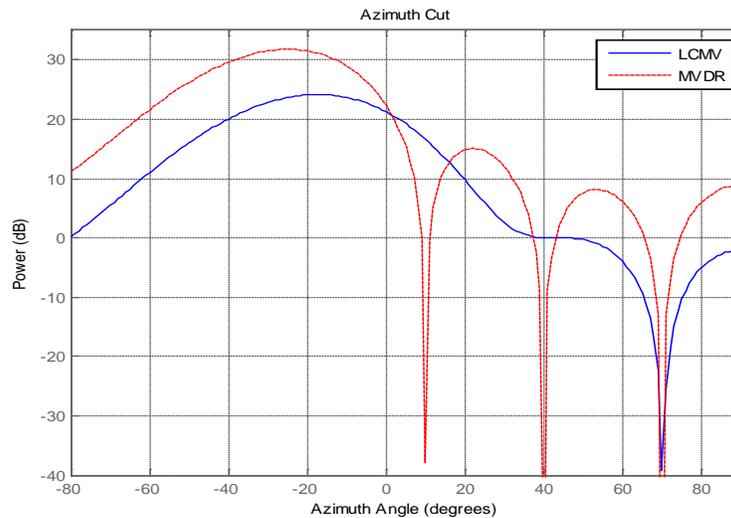


Fig. 8: The self nulling at (10°) in MVDR

MVDR beam formers. It can be noted that the LCMV beam former is able to maintain a flat response region around the 40° in azimuth, while the MVDR beam former creates a null as shown in Fig. 8.

CONCLUSION

This study had presented the beam forming method that has become more popular in wireless mobile communication system. The reason for the popularity is because of the capability to reduce co-channel and interference of neighboring channel. This study had presented two techniques that depend on the received weight vector of the desired signal such as the Minimum Variance Distortionless Response (MVDR) and Linear constraint minimum variance (LCMV). Both these modes gave high output power but they require the direction of all incoming sources, which is difficult to obtain. In fact the LCMV avoid the self nulling even the user very closed from the interference. Thus beam forming has proved its benefits for next generation mobile system and plays a vital role in next generation mobile networks.

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