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Design of Planar Smart Antenna using LMS algorithm

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Abstract—*In modern day wireless systems, there is a need to increase the channel capacity and channel bandwidth for good quality of service. To achieve this Smart Antenna is the best technique which improves the gain of the antenna in the direction of arrival of desired signal (DOA) and null placing in the direction of interferences (DOI). The smart antenna with the aid of adaptive beamforming algorithms Least Mean Square (LMS) achieve the good approximation of weights for a Uniform Linear Array (ULA) and Uniform Planar Array (UPA) of antennas through iterative procedure. In this work, application of LMS algorithm to provide the optimum weights for a linear and planar arraysand their performance are analysed and compared. The simulation results of LMS algorithm are carried out with the help of MATLAB and the beamforming is observed by implementing the inset fed patch antenna array on ANSYS HFSS excited with the optimum weights.*

Keywords—*Smart Antennas, Beam forming, LMS algorithm, Uniform Linear Array (ULA), Uniform Planar Array (UPA)*

I. INTRODUCTION

In modern day wireless systems, many applications in the field of wireless services have been increased which led to the large increment of number of users. This requires a high channel capacity and high channel bandwidth to accommodate all the users and to provide the good quality of service. This demands the high data rates and efficient use of available space for the allocation of user. Capacity can be improved by efficiently beam forming the main lobe in the direction of the user and placing the null in the direction of the interferences.Beam forming is a method used to create the radiation pattern ofan array antenna by constructively adding the weights of thesignals in the direction of interference (DOI) and nulling the pattern in thedirection of DOI. Smart Antenna systems[1] are best systems for this purpose. Development of high speed digital signal processors with complex algorithm computational ability whichare available commercially.

Smart Antennas are basically two types: Switched beamforming smart antennas and Adaptive beamforming smart antennas. Digital signal processor with algorithms and antenna array system together consists of a smart antenna system. Switched beamforming smart antenna systems have predesigned fixed beam patterns along different directions and the algorithm switches between beam patterns based on the signal strength in DOA and DOI.Of which adaptive beamforming is the most advanced and effective approach. In adaptive beamforming smart antenna, the received signal is analysed and undergone into the series of computations and the beam constructively forms in the DOA using the weights evaluated on basis of some criteria. This helps in tracking of the target (user) by continuously receiving and evaluating the weights and in turn feeding to the antenna array system.

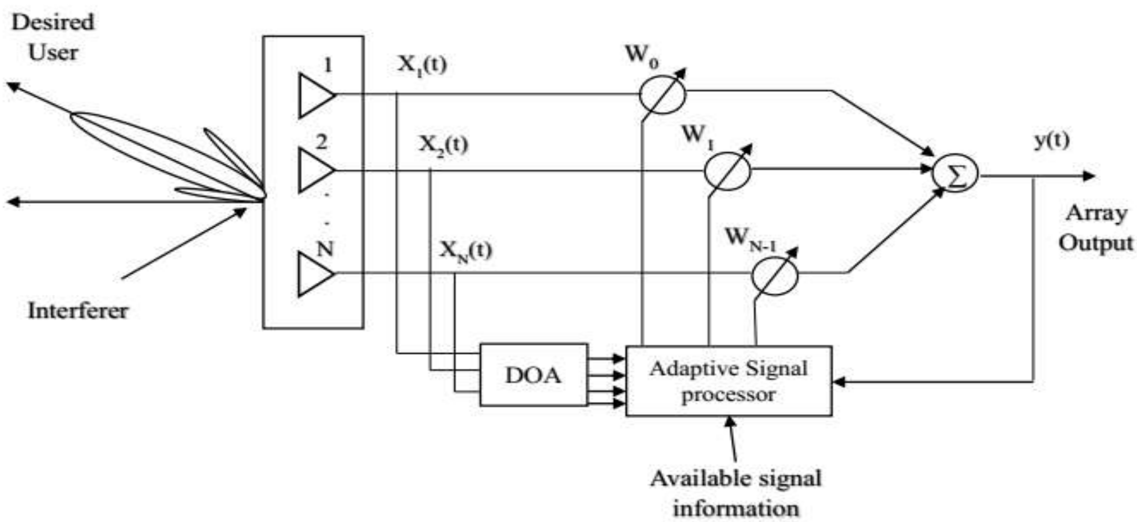

Fig. 1 Block Diagram of Adaptive Smart Antenna System

II. ADAPTIVE SMART ANTENNA

In adaptive beamforming smart antenna systems[2][3], there are two sub classes: blind type and trained or non-blind type. In blind type of adaptive beamforming smart antenna, there is no reference or desired signal and uses the different type of algorithm in which the beamforming is done in DOA without the aid of DOA algorithm. In trained class, there is a DOA algorithm which determines the number of signals of interest and their DOA and number of interferences and their DOI with the help of reference or desired signal. These parameters are inputs to the adaptive beamforming algorithms such as LMS algorithm in this case.

2.1 Least Mean Square (LMS) Algorithm

TheLMS algorithm[5] takes the received signal which consists of noise and compares with the desired signal and estimates the complex weights based on the minimum Mean Square Error (MSE) criteria. This minimum mean square error is achieved based on the gradient of mean square error by steepest descent method. These weights multiplied with received signal induces amplitude and phase changein each of the antenna element of array which changes the direction of the main lobe.

A. LMS algorithm for Uniform Linear Antenna Array (ULA)

The antenna array of size Mx1 receive the incoming signal x(t) and multiplied with the weight vector $\overline{W}$ of size Mx1 which are added up in the transversal filter or time delay filter to give the filter output y(t) and is compared with desired signal d(t) to give error signal e(t). The weights are updated by the gradient of mean square error J with some scaling factor called step size μ through iteration in the direction of minimising the mean square error. The step size varies between generally 0 and 1 which controls the rate of convergence and stability.

$$y(\mathrm{n}) = \sum_{i=0}^{M-1} w(\mathrm{i})\,\mathrm{x}(\mathrm{n-i}) = \overline{W}^T\,\overline{X}(\mathrm{n})$$

$$e(\mathrm{n}) = \mathrm{d(n)} - \mathrm{y(n)}$$

$$\overline{W}(\mathrm{n+1}) = \overline{W}(\mathrm{n}) + \Delta\overline{W}(\mathrm{n})$$

From steepest descent method, the weights converge at the minima of the MSEsurface where gradient of MSE equals zero.

$$\Delta\overline{W}(\mathrm{n}) = -\frac{\mu}{2}\left(\frac{\partial J}{\partial\overline{W}(\mathrm{n})}\right)$$

$$\nabla_{\overline{W}} J = -2\overline{P} + 2\overline{R}\overline{W}$$

where $\overline{R} = \overline{X}(\mathrm{n})\overline{X}^H(\mathrm{n})$ is instantaneous auto correlation matrix of x(n)

$\overline{P} = \overline{X}(\mathrm{n})\,\mathrm{d}^*(\mathrm{n})$ is instantaneous cross correlation between x(n) and d(n)

The weight update vector is

$$\overline{W}(\mathrm{n+1}) = \overline{W}(\mathrm{n}) + \mu\overline{X}(\mathrm{n})e^*(\mathrm{n})$$

B. LMS algorithm for Uniform Planar Antenna Array (UPA)

The two dimensional LMS algorithm[6][7] gives the optimum weights in two dimensional matrix. The antenna array of size MxN receive the incoming signal x(t) and weights of size MxN are multiplied and summed to give the filter output y(t) and the error signal is evaluated for every iteration. The weight matrix is updated with step size μ_p .

Generalised equation for received signal with K number of signal of interests with DOA (θ_i, ϕ_i) and L interferers with DOI (θ_{ni}, ϕ_{ni})

$$X(m,n) = \sum_{i=1}^{K} s_i(\mathrm{t})e^{j\{mkd_x u_i + nkd_y v_i\}} + \sum_{i=1}^{L} n_i(\mathrm{t})e^{j\{mkd_x u_{ni} + nkd_y v_{ni}\}}$$

The weight update matrix is

$$W_{i+1}(m,n) = W_i(m,n) + \mu_p e^* X$$

where $m = 0:\mathrm{M}-1$ and $n = 0:\mathrm{N}-1$

III. DESIGN PROCEDURE

Patch Antenna with resonant frequency (f_r) = 10GHz (X band), dielectric constant of substrate (ε_r) = 2.2 and height of substrate (h) = 0.8mm is designed with inset feeding technique based on the patch antenna design equations and procedure[4]. After optimisation and considerable return loss (< -10dB), the inset fed patch antenna is used to design linear and planar array in ANSYS HFSS as shown in Fig. 2 and Fig. 3 respectively.

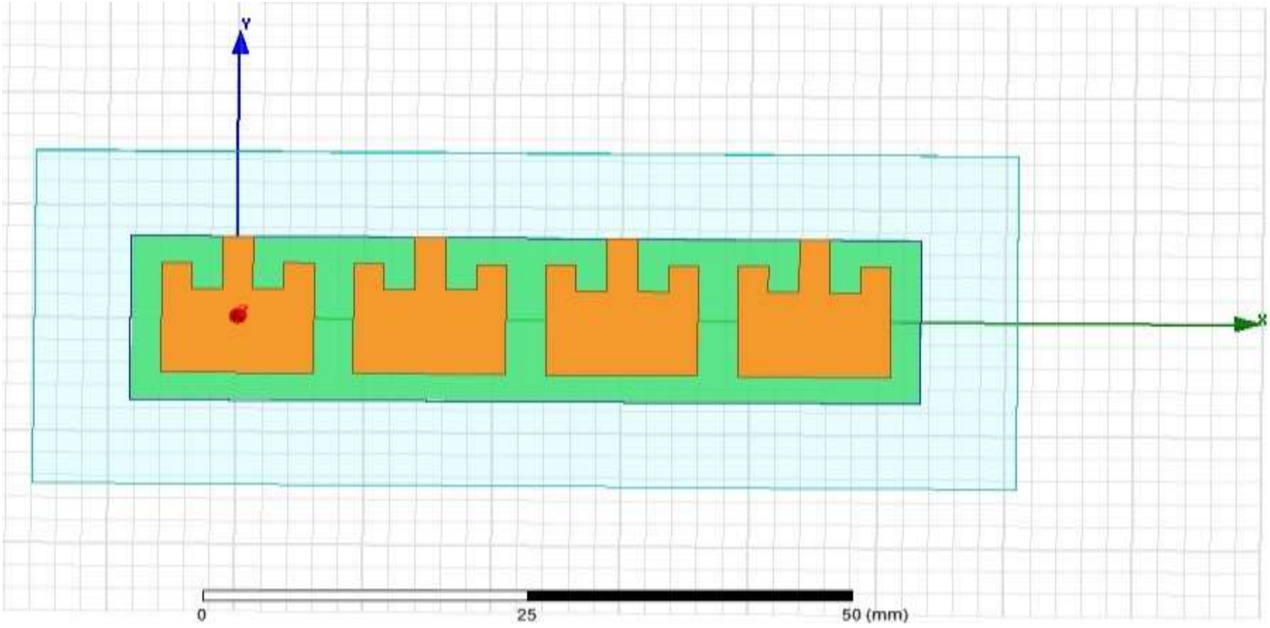

Fig. 2 Linear Array of inset fed patch antenna

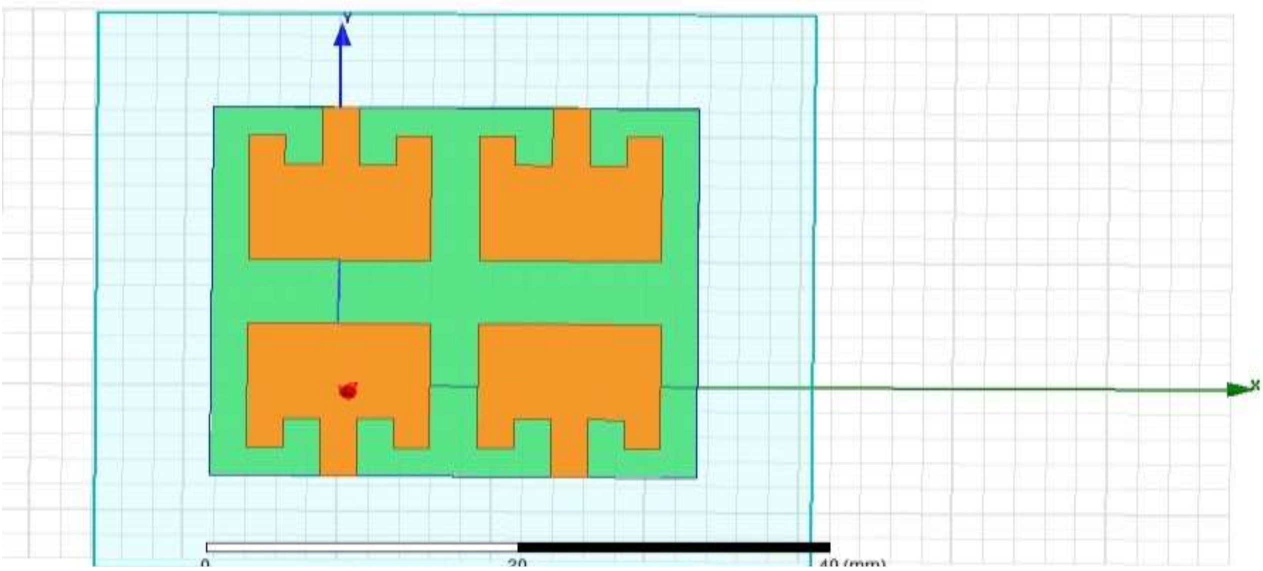

Fig. 3 Planar Array of inset fed patch antenna

IV. SIMULATION RESULTS

For the simulation purpose of LMS algorithm to estimate the weights and to plot the Array Factor MATLAB and to observe the beamforming and radiation pattern ANSYS HFSS is utilised. The distance between the antenna elements (d) = 0.5λ. The weights obtained are used to excite the inset fed antenna arrays

A. Uniform Linear Antenna Array

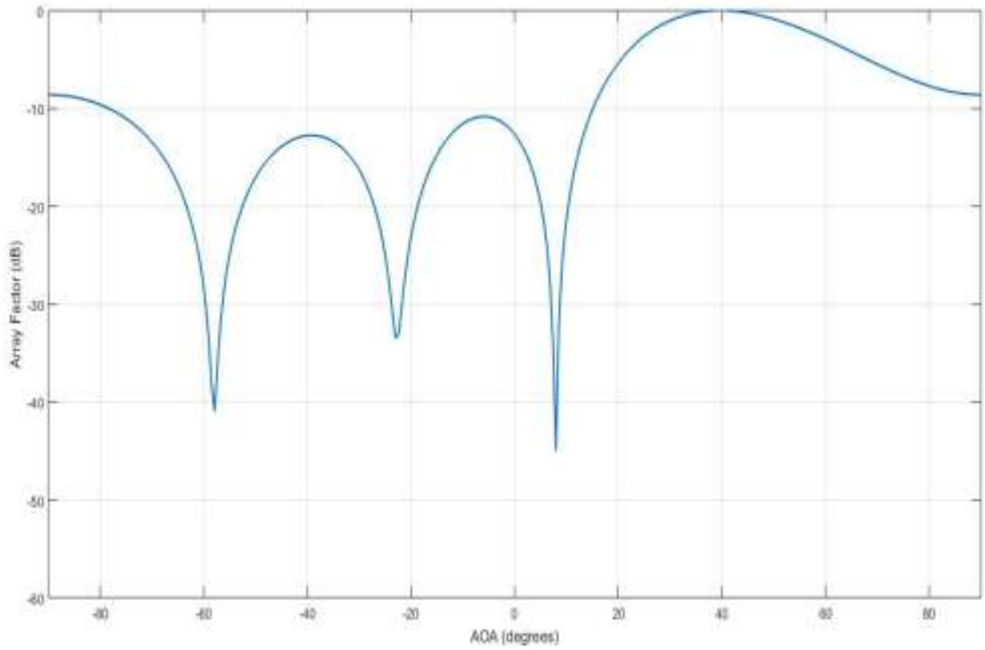

Fig. 4 Array Factor vs AOA for 4x1 antenna array

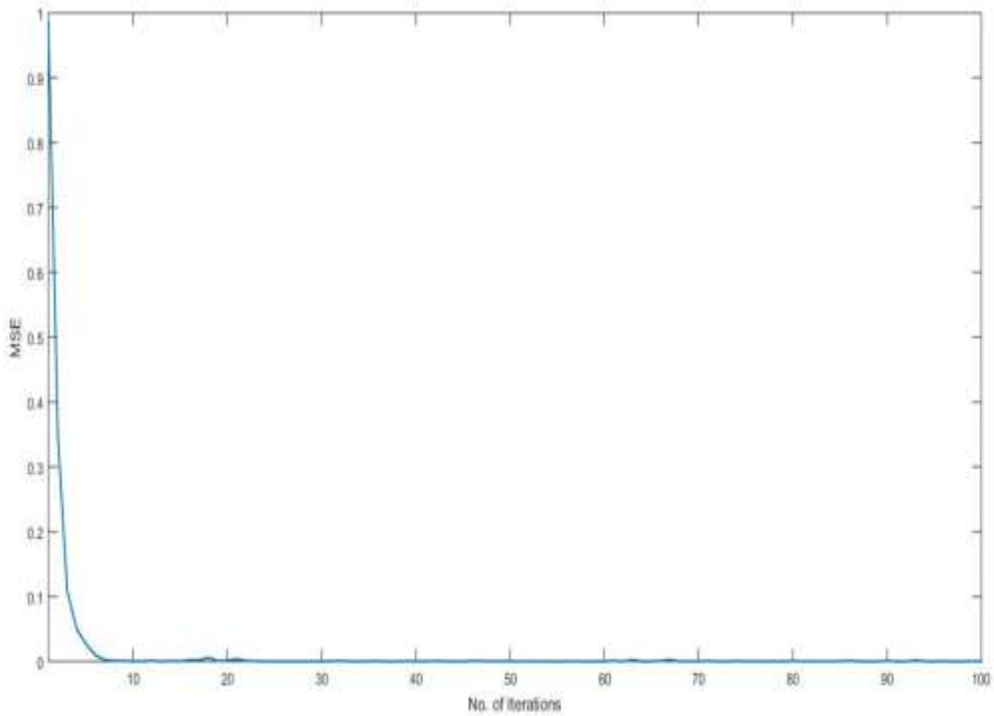

Fig. 5 Mean Square Error (MSE) vs No. of iterations for 4x1 antenna array

The simulations are for M=4 with element spacing d_x=0.5 λ with step index μ =0.1 and SNR =17dB. Angle of interested signal (AOA) is 40^0 and angle of interference (AOI) is -30^0. The process is simulated for 100 iterations. Fig. 4 shows the Array Factor of linear array with various arriving angles. Fig. 5 shows the convergence of weights to optimum where the MSE becomes negligible.

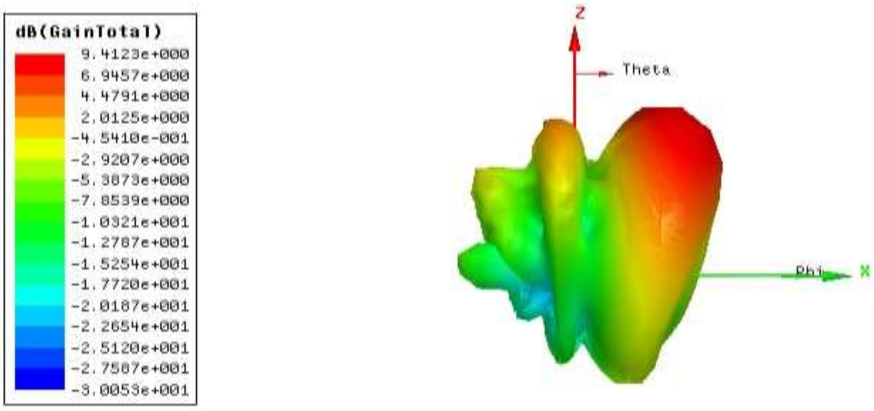

Fig. 6 3D Polar plot of the inset fed patch antenna array 4x1

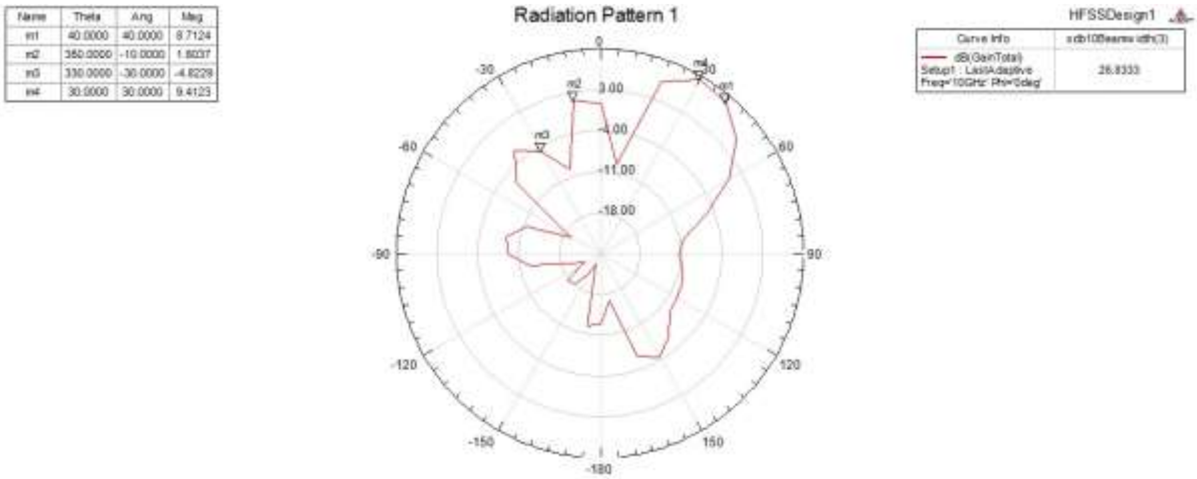

Fig. 7 Radiation Pattern for ϕ ***= 40***^{0}

The optimum weights so obtained are used along with the incoming signal to excite the antenna array in ANSYS HFSS. The linear array is arranged along x-axis where $\phi = 0^0$. Fig. 6 shows the 3D polar plot of the antenna array and Fig. 7 shows the radiation pattern for $\phi = 0^0$.

B. Uniform Planar Antenna Array

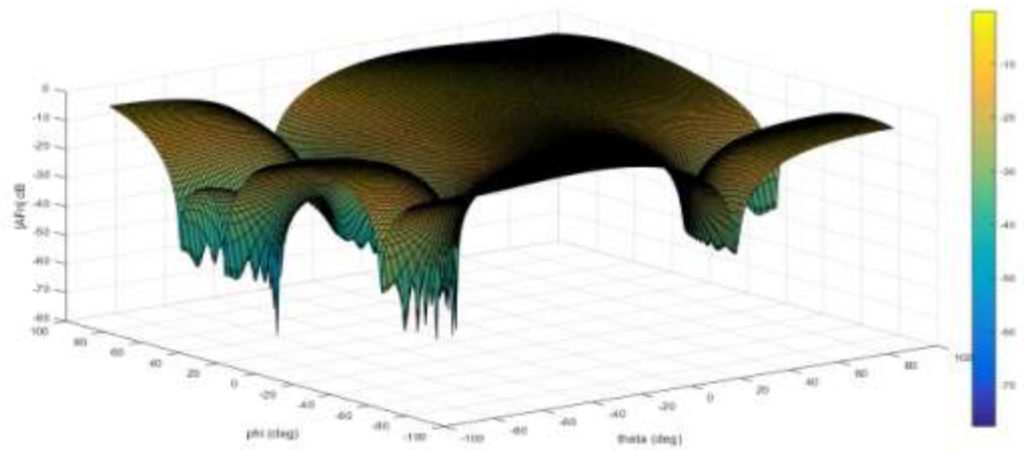

Fig. 8 Array Factor vs AOA for 2x2 antenna array

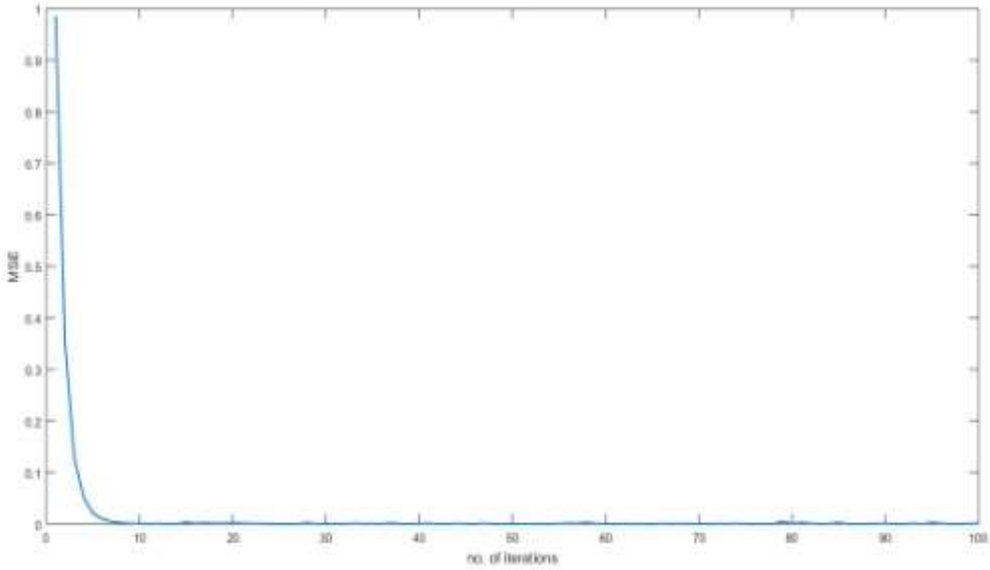

Fig. 9 Mean Square Error (MSE) vs No. of iterations

The antenna elements are arranged in 2x2 with element spacing d_x=0.5 λ and d_y=0.5 λ Simulations are done for 100 iterations with μ=0.1 and SNR is 17 dB. The signal of interest is in the direction of (θ,ϕ)= (40^0, 40^0) and interference in (-30^0, -30^0).

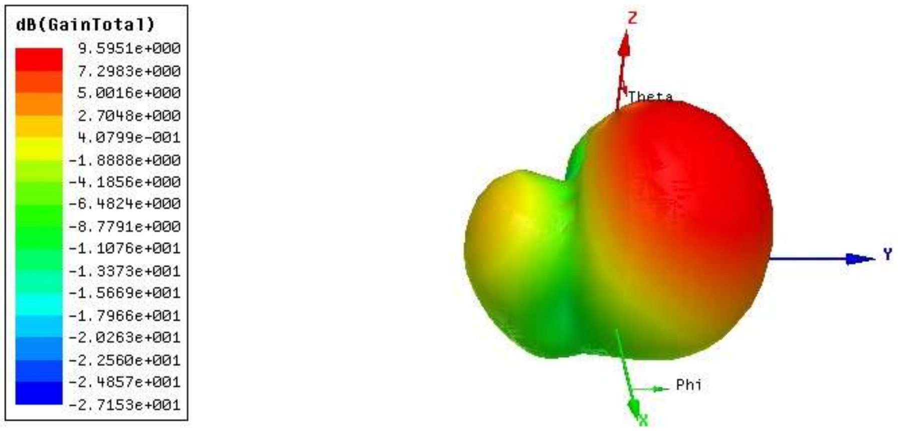

Fig. 10 3D Polar plot of inset patch antenna array of 2x2

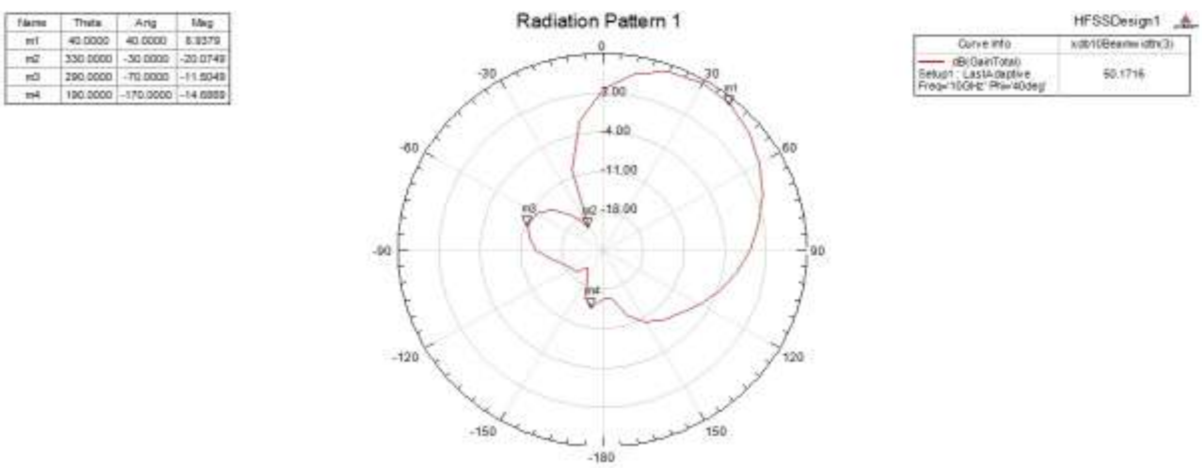

Fig. 11 Radiation Pattern for ϕ =40^0

The optimum weights for the LMS algorithm for planar array are used to excite the antenna array of size 2x2 in ANSYS HFSS to observe the beamforming and the radiation pattern in the direction of desired signal. Fig. 8 shows the 3D polar plot of the antenna array and Fig. 9 shows the radiation pattern for $\phi=40^0$.

Table 1 Comparison of Linear Array and Planar Array

Parameter	Linear Array	Planar Array
Size	4x1	2x2
Iteration Count	10	10
Gain	8.7 dB	8.94 dB
Directivity	8.78 dB	9.46 dB
Interference	-4.8 dB	-20 dB
Peak Sidelobe Level (PSL)	1.6 dB at $(-10^0,0^0)$	-11.5 dB at $(-70^0,40^0)$
Null	-45 dB at $(-8^0,0^0)$	-77.68 dB at $(-65^0,34^0)$
HPBW	26.83^0	50.17^0

V. CONCLUSION

In this work, LMS algorithm for linear array of antennas is implemented in MATLAB for an angle of interest and angle of interference and its performance is analysed. The LMS algorithm is extended to Planar array of antennas simulated and its performance is analysed in MATLAB which shows quick convergence to optimum weights. Both the antennas are implemented in ANSYS HFSS and antenna characteristics are compared based on the Array factor, 3D polar plot and radiation pattern which are tabulated. The uniform planar antenna array shows improvement in Gain, Directivity and Peak Side lobe Level but the Half Power BeamWidth increases in comparison with uniform linear array.

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