Adaptive Array Design using Least Mean Square Algorithm

Vidya P. Kodgirwar, Shankar B. Deosarkar, Kalyani R. Joshi, Arati J. Vyavahare

Abstract: This paper presents the designing and testing of an 8-element linear array for Adaptive Antenna applications using the Least Mean Square (LMS) algorithm towards improving the directive gain of the array. A conventional patch antenna is optimized to operate at 2.35 GHz (4G applications) and this design is extended up to 8 elements using CST Microwave Studio parameterization. The S-parameters, Return Loss, Gain and VSWR of the antenna array are studied for the 2, 4, and 8 elements adaptive array. The simulation results are validated on the hardware setup and found closely matching with the experimental results. The resulting eight-element antenna array geometry is optimized with a coaxial feeding technique. This geometry appears promising in improving the gain from 6.13 to 23.5 dBi for a single element to eight elements respectively. Further, the LMS algorithm is used to compute the optimal complex weights considering different angles for desired User (60° and 30°) and Interferer (10° and 15°) during MATLAB simulation and then these optimal weights are fed to antenna elements using CST for beam steering in a different direction. Maximas are obtained at 54° and 28° when nulls are at 10° and 15° using CST software which is closely matching with MATLAB results.

Keywords: Adaptive antenna array, LMS and RLS algorithms, Beam Steering, S-parameters, Directive Gain, Microstrip Antenna.

I. INTRODUCTION

Wireless communication has been found as an integral part of human life where people can communicate anywhere in the globe at a very high speed. An array of antennas may be used in a variety of ways to improve the performance of a communication system [3]. Perhaps most important is its capability to cancel co-channel interference. An adaptive array works on the assumption that the desired signal and unwanted co-channel interference arrive from different directions. The beam pattern of the array is adjusted to suit the requirements by combining signals from different antennas with appropriate weighting [1]. It also reduces multipath fading, system complexity, cost, BER, and outage probability.

It has been argued that adaptive antennas and the algorithms to control them are vital to a high-capacity communication system development [3]. The smart antenna, as one kind of space-domain technique, has attracted more attention since it can exploit additional system capacity in a matured noise-constrained CDMA system, which has been widely applied in all 3G and 4G standards [3]. In a smart antenna system, complex weights are updated automatically in order to generate the maxima in the desired direction and nulls in the direction of interferer as shown in Figure 1. These arrays improve system capacity and find wide usability in many applications like commercial wireless networks such as LTE, IEEE 802.16, Military Radar applications for scanning and beam-forming, mobile communication, satellite communication, and MIMO systems [9]. The benefits of using smart antenna array beamforming include the improvement of the Mean Square Error (MSE), signal-to-interference-plus-noise ratio (SINR), signal jamming, multipath fading, and directive gain [1]. The term smart antenna is used for a phased array when the weighting on each element is applied in a dynamic fashion [3]. The weights for each channel are not fixed at the time of the array design, rather those weights are computed by the system dynamically while processing the signal to meet the required objectives [3]. The flexibility of array weighting to being adjusted which specify the array pattern plays an important role in the system. A blind area exists between adjacent beams where gain drops dramatically from the peak region, thus, the users may suffer from signal fading or even call drops when moving across this region [5]. Also, the variation in these blind areas increases the complexity in link budget estimation, which is undesirable in system design [5].

In this paper, we have proposed an Adaptive antenna array with 8 elements using CST Microwave Studio [5]. The performance parameters viz. Return Loss, VSWR (Voltage Standing Wave Ratio) and Gain are obtained for single, two, four, and eight elements. Further, the beam steering of the 8 element antenna array is tested with weights computed by the LMS algorithm in MATLAB [5]. For validation of simulation results, the array is fabricated and tested. Experimental results obtained are found closely matching with simulation results. This paper is outlined as; design of microstrip patch antenna is presented in the second section and the geometry of all antennas mentioned above are simulated using CST (Computer Simulation Tool) Microwave Studio is presented in the third section. Prototype testing and results for eight-element array on VNA are presented in the fourth section. The fifth section explains the LMS algorithm with its simulation results using MATLAB for optimal beam steering.

* Correspondence Author
Vidya P. Kodgirwar*, Department of Electronics and Telecommunication Engineering, PES's Modern College of Engineering, SPP University, Pune, India. Email: vidyawattamwar@yahoo.co.in
Shankar B. Deosarkar, Department of Electronics and Telecommunication Engineering, Dr. Babasaheb Ambedkar Technological University, Lonere, Raigad, India. Email: sbdeosarkar@dbatu.ac.in
Kalyani R. Joshi, Department of Electronics and Telecommunication Engineering, PES's Modern College of Engineering, SPP University, Pune, India. Email: krjpune@gmail.com
Arati J. Vyavahare, Department of Electronics and Telecommunication Engineering, PES's Modern College of Engineering, SPP University, Pune, India. Email: aratijv@gmail.com

This section also presents how the LMS algorithm can be used to compute the optimal complex weights considering different angles for desired User and Interferer during MATLAB simulation and then these optimal weights are fed to antenna elements using CST for beam steering. Figure 1 presents functional block diagram for adaptive antenna system. Last section is used to conclude all results.
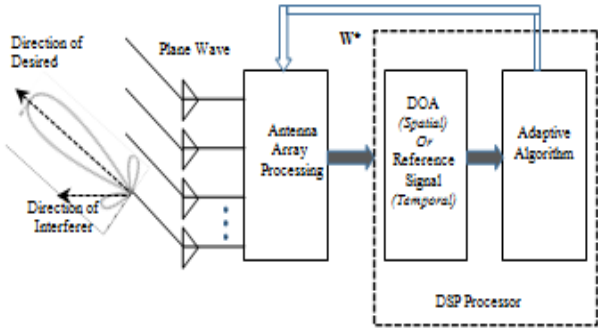

Fig.1. Functional Block Diagram of Adaptive Antenna Array

II. ADAPTIVE ARRAY DESIGN

To design the array, initially, single element antenna designing is necessary. This antenna is designed using standard equations given in [17]. Various performance parameters of antenna, like S-Parameters, Return Loss, VSWR and Directive Gain are evaluated around 2.35 GHz for a single element, 2 element array, 4 element array and then for 8 element array using CST. Rogers RT/Duroid 5870 material is used as the substrate with the dielectric constant of 2.33 and thickness (height) 1.575 mm.

These derived dimensions for single element antenna are shown in Table I. Further the same dimensions are used to construct array geometry with $\lambda/2$ inter-element spacing as shown in figure 1.

Table I: Design Specifications for Single Element

Sr. No.	Parameter	Value
1.	Operating Frequency	2.3 GHz
2.	Width of Patch (W)	40 mm
3.	Length of Patch	30 mm
4.	Thickness of Patch	0.07 mm
5.	Height of Substrate	1.575 mm

In linear beam-steering array, elements are equally spaced and maximum radiation is a function of phase and amplitude distribution of excitation signal. The phase shift applied to each element decides the direction of maxima and amplitude decides the shape of the radiation pattern. If array elements are placed in the x-axis, a radiation pattern formed in xz-plane can be realized as a fully adjustable weighting factors vector multiplied by a space distribution vector as given in (1).

$$P(\theta) = Pe(\theta)Pa(\theta) = Pe(\theta)\begin{bmatrix} A_1 e^{j\psi 1} \\ A_2 e^{j\psi 2} \\ \vdots \\ A_n e^{j\psi m} \end{bmatrix}\begin{bmatrix} e^{j2\pi\left(\frac{d1}{\lambda}\right)\sin(\theta)} \\ e^{j2\pi\left(\frac{d2}{\lambda}\right)\sin(\theta)} \\ \vdots \\ e^{j2\pi\left(\frac{dn}{\lambda}\right)\sin(\theta)} \end{bmatrix} \quad ....(1)$$

Where $Pe(\theta)$ and $Pa(\theta)$ are the element pattern and array factor, respectively, in angular position θ at the xz-plane, and

$A_n e^{j\psi_n}$ and *dn* represent the nth element complex weighting factor and distance from central position respectively.

III. SIMULATION RESULTS OF THE ARRAY

As explained in the previous section, the optimized geometry for a single element to eight elements is simulated in CST and VSWR, return loss, radiation pattern, and S-Parameters are observed. All simulation results are presented in Table 2. The geometry of the eight-element array is shown in Figure 1. VSWR, return loss and radiation pattern for the eight-element array are shown in Figures 2-4 respectively. Single element antenna is designed using standard equations given in [7]. This design is further optimized and extended up to eight elements to obtain optimal parameters. All performance parameters are compared and presented in Table II, and it has been noticed that, when the number of array elements is increased, a directive gain of the array also increases. Directive gain is improved from 6.2 dBi to 23.5 dBi.Return loss and VSWR are also increasing with a number of elements that are not desirable but still, these values are found acceptable.
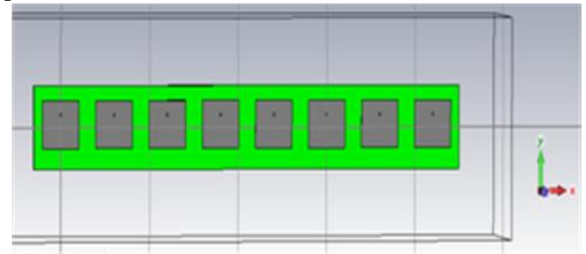

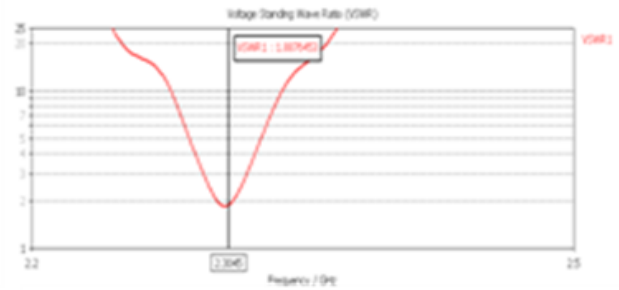**Fig. 1. Geometry of Eight Element Array, using CST.**
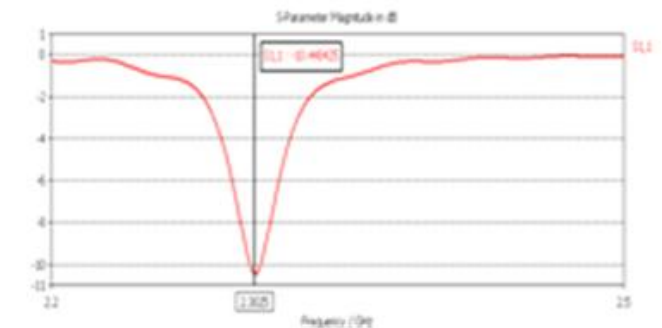

Fig. 2. VSWR Measurement for Eight Element Array.

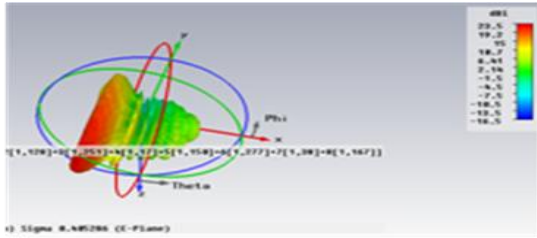**Fig. 3. Return Loss measurement for Eight Element Array.**

Fig. 4. 3D Radiation Pattern of Eight Element Array.

IV. PROTOTYPE TESTING AND RESULTS

Antenna arrays are the mechanism by which we can realize complex radiation patterns without significantly altering the antenna impedance. Usually, the radiation pattern of a single element is relatively wide and provides a low value of directive gain. For many array applications, the high directive gain is necessary [1]. For practical needs, this is accomplished by increasing the electrical size of the antenna, which means increasing the number of array elements.

Table II: Result Analysis of Various Arrays

Sr. No.	Parameter	Values for Single Element	Values for Two Element Array	Values for Four Element Array	Values for Eight Element Array
1.	Return Loss	-15.47 dB	-20.48 dB	-15.091 dB	-10.44 dB
2.	Reflection Coefficient	0.194	0.173	0.243	0.299
3.	VSWR	1.49	1.56	1.88	1.85
4.	Directive Gain	6.2dBi	9.1dBi	12.7dBi	23.5dBi

All designs discussed in earlier sections for the eight-element array are fabricated and measurements are taken using Vector Network Analyzer (VNA). The front side of this array is presented in Figure 5. Measured values of Return Loss and VSWR are indicated in Figures 6 and 7. All measured results are found closely matching with simulation results.

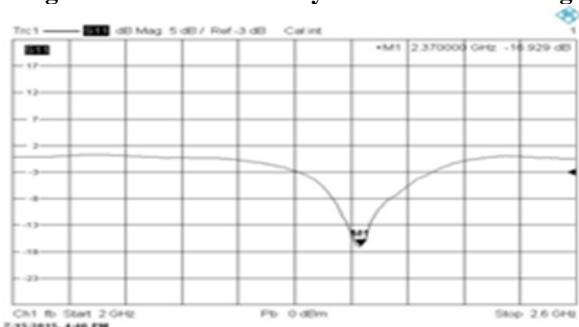**Fig. 5. Front Side of Array with Coaxial Feeding**

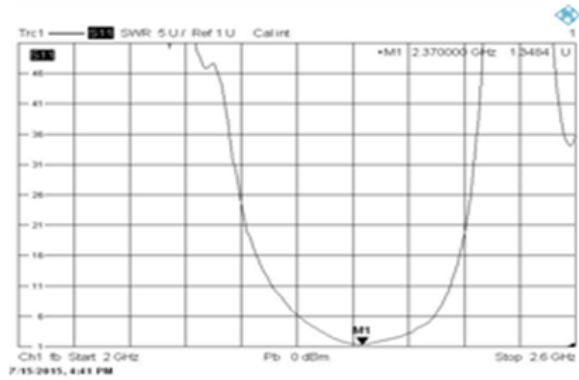**Fig. 6. Measured Return Loss using VNA (-16.9 dB)**

Fig. 7. Measured VSWR using VNA (1.84)

V. WEIGHT ESTIMATION USING LMS ALGORITHM

The optimal directive gain of adaptive array is determined by the optimality of the weights applied to the individual elements excitation signals. Least Mean Square (LMS) algorithm is one of the most popular algorithms to determine these optimal weights. The LMS algorithm is a gradient-based approach and it incorporates an iterative procedure that makes successive corrections to the weight vector in the direction of the negative of the gradient vector which eventually leads to the minimum mean square error at the current time [11].

In LMS algorithm optimal weight after each iteration is computed using (2);

$$W(n+1) = W(n) - \mu_g (W(n)) \quad \ldots (2)$$

Whe

re W(n+1) denotes the new weights computed at the $(n+1)^{th}$ iteration and μ is a positive scalar (gradient step size) that controls the convergence characteristics of the algorithm, and g(w(n)) is an unbiased estimate of the MSE gradient. For a given w(n), the MSE is given by,

$$\xi(W(n)) = E[|r(n+1)|^2] + W^H(n)RW(n) - W^H(n)Z - Z^HW(n) \quad \ldots (3)$$

Where r(n+1) is a reference signal sample and R is an array correlation matrix. The MSE gradient at the nth iteration is obtained by differentiating above equation (3) with respect to w, yielding

$$\nabla_W \xi(W)|_{W=W(n)} = 2RW(n) - 2Z \quad \ldots (4)$$

At the $(n+1)^{th}$ iteration, the array is operating with weights w(n) computed at the previous iteration; however, the array signal vector is x(n+1), the reference signal sample is r(n+1), and the array output is

$$Y(W(n)) = W^H(n)*X(n+1) \quad \ldots (5)$$

LMS algorithm uses an estimate of the gradient by replacing R and z by their noisy estimates available at the $(n+1)^{th}$ iteration, leading to

$$g(W(n)) = 2X(n+1)X^H(n+1)W(n) - 2X(n+1)r^* (n+1) \quad \ldots (6)$$

Since the error ε(w(n)) between the array output and the reference signal is given by

$$\varepsilon(W(n)) = r(n+1) - W^H(n)X(n+1) \quad \ldots (7)$$

It follows from equation (6) that,

$$g(W(n)) = -2X(n+1)\varepsilon^*(W(n))\ldots\ldots\ldots(8)$$

Thus, the estimated gradient is a product of the error between the array output and the reference signal and the array signals after the nth iteration. Taking the conditional expectation on both sides of (6), it can easily be established that the mean of the gradient estimate for a given w(n) becomes

$$\overline{g}(W(n)) = 2RW(n) - 2Z\ldots\ldots\ldots(9)$$

Where $\overline{g}(W(n))$ denotes the mean of the gradient estimate for a given $W(n)$. From (4) and (9) it follows that the gradient estimate is unbiased. Compared to other LMS algorithm is relatively simple. It does not require correlation function calculation nor does it require matrix inversions [5].
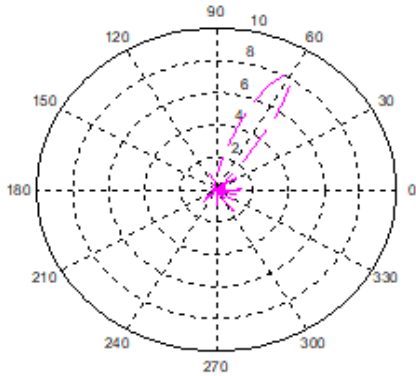

**Fig. 8. Polar Plot using MATLAB.
Desired user at 60° and interferer at 10°**

LMS algorithm is simulated using MATLAB for eight elements with 2.35 GHz frequency and the complex weights created have been used for excitation of the array in the CST Microwave Studio. It has been observed that simulation results for beam steering in CST are almost the same as it is observed in MATLAB. While simulating the LMS algorithm in MATLAB, initially it has been assumed that the user is at 60° and interferer is at 10°. Figure 8 indicates a polar plot using MATLAB, in which the beam is generated in the direction of the user (60°) and null is introduced in the direction of interferer (10°). Figure 9 indicates a polar plot using CST after feeding weights computed by the LMS algorithm, that is the desired user is at 54° and interferer at 10°. Figures 10 and 11 represent the same type of results for the user at 30° and interferer at 15° in MATLAB, and CST gives the maxima at 28° and null at 15° respectively.
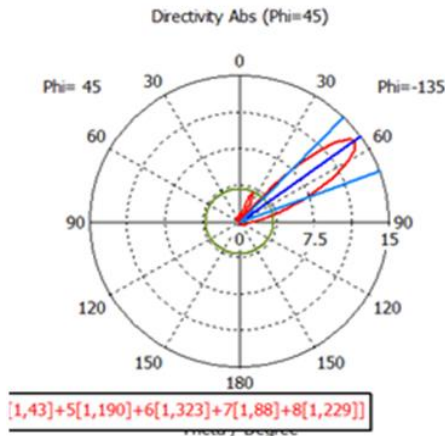

**Fig. 9. Polar Plot using CST after feeding Weights
Computed by LMS Algorithm. Desired user at 54o and
interferer at 10o**

VI. CONCLUSION AND FUTURE SCOPE

An adaptive antenna array with eight elements resonating at 2.35 GHz for LTE applications is proposed in this paper. The proposed antenna array gives a high gain in the desired direction of the user and minima in the direction of the interferer. CST Simulation results are analyzed for VSWR, Return Loss, and Directive Gain with one, two, four, and eight antenna elements. It has been verified that when we increase the array elements, the directive gain also increases from 6.2 dBi to 23.5 dBi. Optimal beam steering is also achieved by estimating complex weights using the LMS algorithm in MATLAB and these weights are applied to array elements using CST. For these MATLAB simulations, two different angles are considered for User (60° and 30°) and Interferer (10° and 15°). Maxima is obtained at 54° and 28° when Nulls are at 10° and 15° using CST which is closely matching with MATLAB results. It has been observed that with simple design and proper optimization, Directive Gain of proposed array design is improved compared to [4, 5, 15, 16, and 17].

The experimental setup validates the simulation results. The obtained results are encouraging and promise their usability for 4G and 5G S-Band applications. The future research direction would explore the time-varying user and interferer locations, a number of simultaneous users and interferer, other novel weight estimation algorithms for beam steering applications.
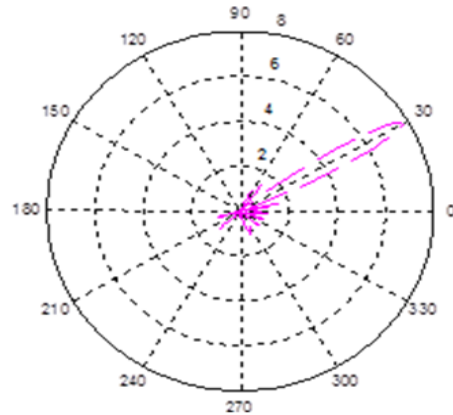

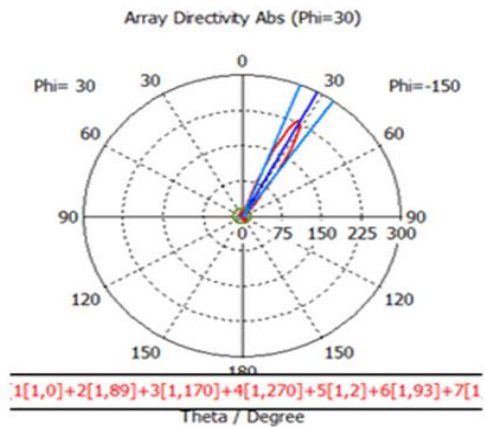**Fig. 10. Polar Plot using MATLAB. Desired user at 30o
and interferer at 15o**

**Fig. 11. Polar Plot using CST after feeding Weights
Computed by LMS Algorithm. Desired user at 28o and
interferer at 15o**

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AUTHORS PROFILE

Vidya Pramod Kodgirwar received her degree in Electronics and Telecommunication in 2001 from Government College of Engineering, Aurangabad and Master's degree in Electronics Engineering from JNEC, Dr. BAM University, Aurangabad, Maharashtra, India. Presently she is pursuing her Ph.D. from SPPU, Pune. She is now an Assistant Professor at the Department of Electronics and Telecommunication Engineering, PES's Modern College of Engineering, SPP University, Pune. Her research interests are focused on Adaptive Antenna Design and Beam-forming algorithms as well as Embedded System Designs. She has (co)authored more than 20 research papers in international refereed journals and conferences. (email:vidyawattamwar@yahoo.co.in)

Shankar B. Deosarkar received Ph.D. in Electronics Engineering from SGGS College of Engineering and Technology Nanded, Swami Ramanand Tirth Marathwada University, Nanded. Presently he is working as a Professor in the Department of E&TC of Dr. Babasaheb Ambedkar Technological University, Lonere. His research interests are in EMI/EMC, Wireless Communication, Micro-Strip Antenna Design, and Optical Communication. His Research Publications in the International Journals and Conferences are more than 120. He is working in the present university as a first faculty since January 1990 and had worked in various capacities such as Controller of Examinations, Professor, Professor and Head of the Department, Principal, Member of Academic and Executive Council, Member of IETE, IEEE, for more than 25 years. (email:sbdeosarkar@yahoo.com).

Kalyani R. Joshi received her Ph.D. in Electronics Engineering from College of Engineering Pune, SPP University, Pune, Maharashtra. Presently she is working as a Professor in the Department of E&TC of PES's Modern College of Engineering, Pune. Her research interests are in Signal Processing, Image Processing, Wireless Communication, Micro-Strip Antenna Design, and Optical Communication. Her Research Publications in the International Journals and Conferences are more than 40. She had worked in various capacities such as Principal, Controller of Examinations, Professor and Head of the Department, Chair of WIE-IEEE Affinity Group, Member of Academic and Executive Council, CAP Director, Member of MISTE, FIETE, Senior Member IEEE, for more than 25 years. (email:krjpune@gmail.com)

Arati J. Vyavahare completed her graduation in Electronics and Telecommunication Engineering, post-graduation in Electronics and Telecommunication Engineering from COEP, Pune and Ph.D. in Electronics and Telecommunication Engineering, image processing. The author has filed and published 2 Patents, one copyright registered in Still image an moving picture compression standards. The author is having work experience of more than 20 years in the industry and teaching field. The author worked in various areas of image and segmentation analysis in computer vision and image processing as well as in Biomedical signal processing. She received the 'Best Research Paper' award in IEEE Sponsored international conference. Published more than 56 papers in different conferences and journals. She is Life member of ISTE, IETE and ISRD Professional society.(email: aratijv@gmail.com)

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