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Performance Evaluation of Adaptive Array Antenna using Least Mean Square Algorithm

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Abstract : This paper presents the design and testing of an 8-element linear array for Adaptive Array applications using the Least Mean Square (LMS) algorithm for the improvement of directive gain of the array. A conventional microstrip patch antenna has been optimized to operate at 2.3GHz (4G and 5G 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 antenna. The simulation results are validated on the hardware setup and these are found closely matching with the experimental results. The final eight-element antenna array geometry is fabricated using the coaxial feeding technique. This geometry appears promising in improving the gain from 6.13 to 15.5dBi for a single element to eight elements respectively. Further, the LMS algorithm is used to compute the optimal complex weights considering different angles for user of interest (60o and 30o) and Interferer (10o and 15o) during MATLAB simulation and then these computed complex weights are applied to antenna elements using CST for beam steering in a different direction. Maxima's are obtained at 54o and 28o when nulls are at 10o and 15o during CST simulation, and it has been noticed that these results are closely matching with MATLAB results. test the APT. The macroeconomic variables include inflation, oil prices, interest rate and exchange rate. For the very purpose monthly time series data has been arranged from Jan 2010 to Dec 2014. The analytical framework contains**.**

Index Terms **- Adaptive Antenna, Directive Gain, Direction of Maxima, Direction of Null, Interferer Direction**

S-Parameters.

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 [1-2]. Perhaps most important is its ability to cancel co-channel interference. An adaptive array antenna 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 [3]. It also reduces multipath fading, system complexity, cost, Bit Error Rate, 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 [4-6]. The smart antenna, as one kind of space-domain technique, has attracted more attention because it can exploit additional system capacity in a matured noise-constrained CDMA system, which has been widely applied in all 3G and 4G standards [7]. In an adaptive antenna system, complex weights are updated automatically 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 beamforming, mobile communication, satellite communication, and MIMO systems [8-9].

The benefits of using adaptive antenna array beamforming includes the improvement of the Mean Square Error (MSE), signal-to-interference-plus-noise ratio (SINR), signal jamming, multipath fading, and directive gain [10]. The term adaptive antenna is used for a phased array when the weighting on each antenna element is applied in a dynamic fashion [11]. The weights for each channel are not fixed initially when array was designed, rather those weights are computed by the system dynamically while processing the signal to meet the required objectives [11]. The flexibility of array weighting to being adjusted which specify the beam 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 [12-14]. Also, the variation in these blind areas increases the complexity in link budget estimation, which is undesirable in system design [15-16].

In this paper, we have proposed an adaptive antenna array with 8-elements using CST Microwave Studio and MATLAB. The performance parameters viz. Return Loss, VSWR and Directive Gain are observed for single, two, four, and eight elements. Further, the beam steering capabilities of the 8-element array is tested with weights computed by the LMS algorithm in MATLAB. 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 1, 2, 4, and 8 element antennas are simulated using CST Microwave Studio is presented in the third section. Fourth section presents prototype testing and results for eight-element array using VNA (Vector Network Analyzer). The fifth section 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[17-18] presents functional block diagram for adaptive antenna system. Last section is used to conclude all results.

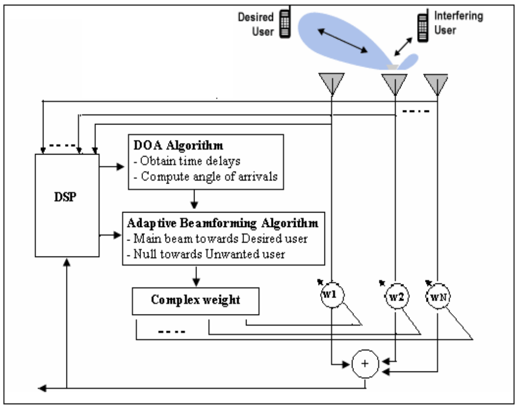


Figure 1. Functional Block Diagram of Adaptive Antenna System

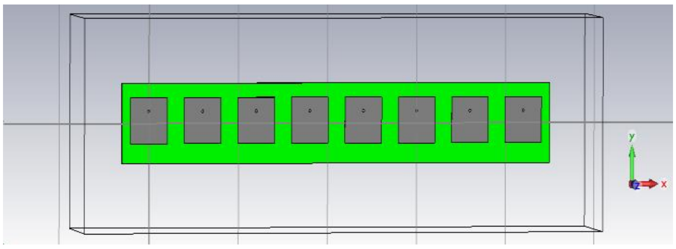


Figure 2. Geometry of Eight Element

II. ADAPTIVE ARRAY DESIGN

To design the array, initially, single element antenna designing is required. This antenna is designed using standard equations given in [19-21]. This is microstrip patch antenna with coaxial feed technique. Various performance parameters of antenna, like S-Parameters, Return Loss, VSWR and Directive Gain are evaluated around 2.35GHz. Further this design is extended for 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) 1.575mm. These optimized dimensions for single element antenna are shown in Table 1. Further the same antenna element dimensions are used to construct array geometry with λ/2 inter-element spacing as given in Figure 2.

2.1 Design Specifications for Single Element Antenna

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 applied to antenna elements. The phase shift applied to each element decides the direction of maxima and null 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 an adjustable weighting factors vector multiplied by a space distribution vector as given in (2.1).

$$P(\theta) = Pe(\theta)Pa(\theta) = \begin{bmatrix} A1e^{j\varphi 1} \\ A2e^{j\varphi 2} \\ \cdot \\ \vdots \\ \cdot \\ Ane^{j\varphi n} \end{bmatrix} \begin{bmatrix} e^{j2\pi\left(\frac{d1}{\lambda}\right)\sin(\theta)} \\ e^{j2\pi\left(\frac{d2}{\lambda}\right)\sin(\theta)} \\ \cdot \\ \vdots \\ \cdot \\ e^{j2\pi\left(\frac{dn}{\lambda}\right)\sin(\theta)} \end{bmatrix} \text{........................} \quad (2.1)$$

Where, Pe(θ) and Pa(θ) are the element pattern and array factor, respectively, at angular position θ in the xz-plane, and Ane jΨn and dn represent the nth element complex weighting factor and distance from central position respectively.

III. SIMULATION RESULTS OF THE ARRAY

As mentioned in the previous section, the optimized geometry for a single element to eight elements is simulated in CST and Voltage Standing Wave Ratio (VSWR), return loss, radiation pattern, and S-Parameters are observed. All simulation results from single element to eight element arrays 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 3-5 respectively. Single element antenna is designed using standard equations given in [22-23].

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 6.2dBi to 23.5dBi. Return loss and VSWR are also increasing with a number of elements which is not desirable but still, these values are found in the acceptable range.

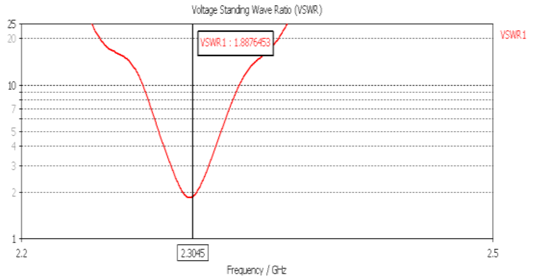


Figure 3. VSWR Measurement for Eight Element ArrayAntenna

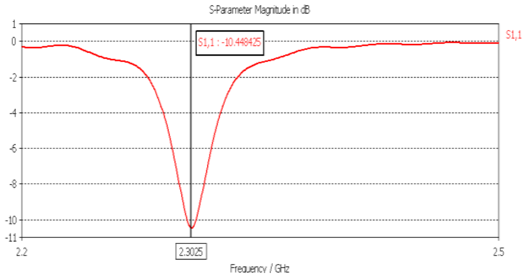


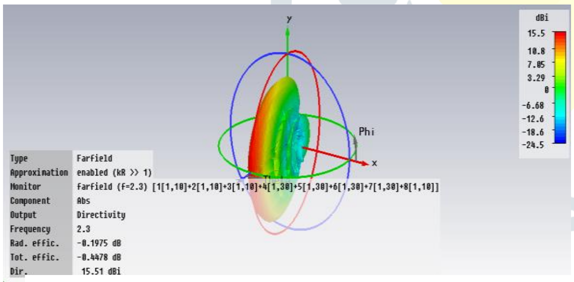
Figure 4. Return Loss measurement for Eight Element Array Antenna

IV. HARDWARE TESTING AND RESULT DISCUSSION

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 [24]. For practical needs, this is accomplished by increasing the electrical size of the antenna, which means increasing the number of array elements.

4.1 The performance of Array with different Elements

Sr. No.	Parameter	Value for Single Element	Value for Two Element	Value for Four Element	Value for Eight Element
1.	Return Loss	-15.47dB	-20.48dB	-15.091dB	-10.44dB
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	15.5dBi



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=2.3) [1[1,10]+2[1,10]+3[1,10]+4[1,30]+5[1,30]+6[1,30]+7[1,30]+8[1,10]]
Component	Abs
Output	Directivity
Frequency	2.3
Rad. effic.	-0.1975 dB
Tot. effic.	-0.4478 dB
Dir.	15.51 dBi

Figure 5. Radiation Pattern (3D) with Directivity 15.5dBi

Figure 6. Hardware for Eight Element Adaptive Array Antenna using Coaxial Feeding

All designs [illegible] ray a [illegible] Network Analyzer (VNA). The front side of this array is presented in Figure 6. Measured values of Return Loss and VSWR are indicated in Figures 7 and 8. All measured results has been found closely matching with simulation results.

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 element's 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 [25].

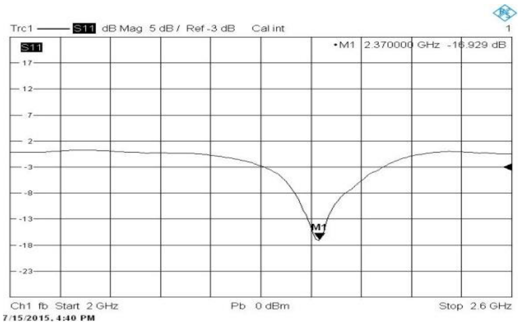


Figure 7. Return Loss Measurement of Array Prototype using Network Analyzer (-16.9dB)

Figure 8. VSWR Measurement of Array Prototype using Network Analyzer (1.84)

In LMS algorithm optimal weight after each iteration is computed using (5.1).

$$W(n+1) = W(n) - \mu_g\big(w(n)\big) \ldots\ldots\ldots\ldots\ldots\ldots (5.1)$$

Where 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,

$$\xi\big(W(n)\big) = E[|r(n+1)|^2] + W^H(n)RW(n) - W^H(n) - Z^H W(n) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.2)$$

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

$$\nabla_w\, \xi\,(W)|_{w=w(n)} = 2RW(n) - 2Z \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.3)$$

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

$$Y\big(W(n)\big) = W^H(n) * X(n+1) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (5.4)$$

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

$$g\big(W(n)\big) = 2X(n+1)X^H(n+1)W(n) - 2X(n+1)r^*(n+1) \ldots\ldots\ldots\ldots\ldots\ldots\ldots. (5.5)$$

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

$$\mathcal{E}\big(W(n)\big) = r(n+1) - W^H(n)X(n+1) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.6)$$

It follows from equation (5.5) that,

$$g\big(W(n)\big) = -2X(n+1)\mathcal{E}^*\big(W(n)\big) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.7)$$

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

$$\tilde{g}\,\big(W(n)\big) = 2RW(n) - 2Z \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.8)$$

Where $\tilde{g}\,\big(W(n)\big)$ denotes the mean of the gradient estimate for a given w(n). From (5.3) and (5.8) it follows that the gradient estimate is unbiased. Compared to other, the LMS algorithm is relatively simple. It does not require matrix inversion [6] but it is suitable only in a static environment.

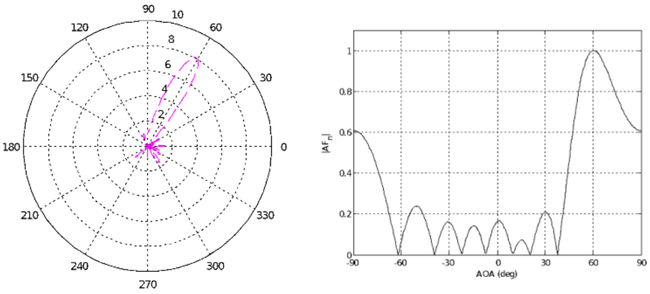


Figure 9. Polar Plot (Left) and Rectangular Plot (Right) using MATLAB (Desired user: 60^{o} and interferer: 10^{o})

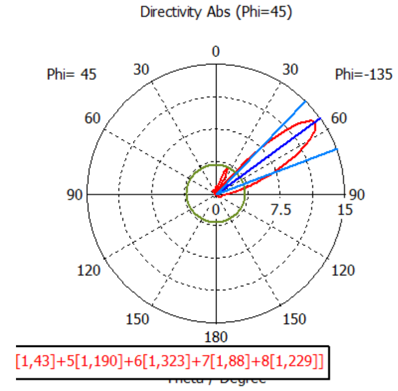


Figure 10. Polar Plot obtained using CST (Main lobe direction for desired user is 56^{o} and interferer direction is 10^{o})

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^{o} and interferer is at 10^{o}. Figure 9 indicates a polar plot and rectangular plot using MATLAB, in which the beam is generated in the direction of the user (60^{o}) and null is introduced in the direction of interferer (10^{o}). Figure 10 indicates a polar plot using CST after feeding weights computed by the LMS algorithm, that is the desired user is at 54^{o} and interferer at 10^{o}. Figures 11 and 12 represent the same type of results for the user at 30o and interferer at 15^{o} in MATLAB, and CST gives the maxima at 28^{o} and null at 15^{o} respectively.

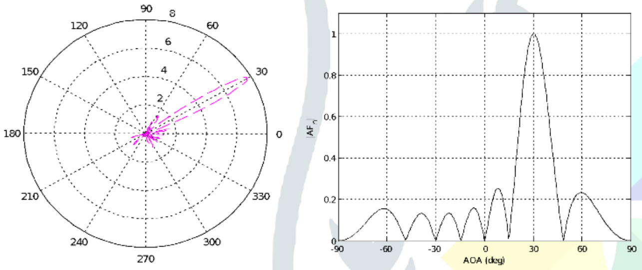


Figure 11. Polar Plot (Left) and Rectangular Plot (Right) using MATLAB (Desired user: 30^{o} and interferer: 15^{o})

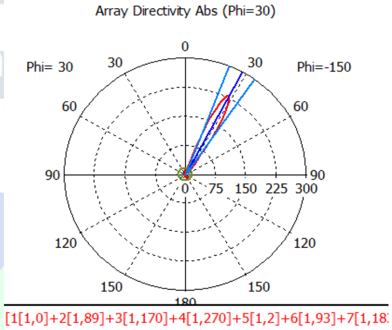


Figure 12. Polar Plot obtained using CST (Main lobe direction for desired user is 28^{o} and interferer direction is 15^{o})

VI. CONCLUSION AND FUTURE SCOPE

An adaptive antenna array with eight elements resonating at 2.35GHz for LTE applications is proposed in this paper. The proposed antenna array gives a high gain in the desired direction of the user and minimum gain (null) 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 observed that when we increase the array elements, the directive gain also increases from 6.2dBi to 15.5dBi. 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^{o} and 30^{o}) and interferer (10^{o} and 15^{o}). Maxima is obtained at 54^{o} and 28^{o} when Nulls are at 10^{o} and 15^{o} in 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 has been improved.

The experimental setup using VNA 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.

VII. SPECIAL ACKNOWLEDGMENT

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