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# Adaptive Beam Formation in Smart Antenna – A New Combined Method Using Tchebyscheff Distribution and Constrained Stability Least Mean Square Algorithm

Subhashree Nibedita Baliarsingh*, Anupama Senapati, Arindam Deb and Jibendu Sekhar Roy

School of Electronics Engineering, KIIT University
Bhubaneswar 752014, Odisha, India

**Corresponding author's email: subhashreeb4 [AT] gmail.com,*

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**ABSTRACT—** ***Adaptive beam-formation in smart antenna using constraint stability least mean square (CSLMS) algorithm along with Tchebyscheff distribution (TDCSLMS) is reported in this paper. Different values of pre-defined side lobe levels are considered for Tchebyscheff distribution. The results of adaptive beam formation are compared with respect to desired beam direction, null direction, beamwidth and maximum side lobe level (SLL). Using TDCSLMS, lower side lobe levels are achieved compared to CSLMS for various angles of desired user and undesired interferer.***

**Keywords—** Smart antenna, constrained stability least mean square algorithm, Tchebyscheff distribution, side lobe reduction

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## 1. INTRODUCTION

Overall performance in mobile communication can be improved by using adaptive smart antenna which is an antenna array with smart signal processing unit. Smart antenna after estimating direction of arrival (DOA), generates radiation beam along the desired user and produces null towards the undesired interferer [1-2]. Huge power saving is possible using smart antenna in mobile communication in addition to enhancement of signal quality, network capacity and coverage area. Usually the signals received at the different antennas are multiplied with complex weights and then adaptively weights are summed up. Basically, there are two types of smart antennas, viz., switched beam smart antenna and adaptive smart antenna. In switched beam smart antenna, antenna system has several fixed beam patterns and according to detected condition most appropriate beam is used for communication. Whereas, in adaptive smart antenna, beam can be steered in any direction according to DOA estimation and at the same time null can be generated in the direction of the interferer. Smart antenna estimates direction of arrival of incoming signals and the direction of interfering signals. Then using beam-forming algorithm, antenna beam is generated toward the desired direction and null is generated toward the direction of interferer. There are various types of algorithms for beam-forming, having their advantages and disadvantages [3-7]. In addition to various methods of DOA estimations, many iterative schemes applicable to adaptive beam-forming have been described in [3]. A sequential quadratic programming based algorithm is used for multi-lobe pattern and for adaptive nulling of the pattern in [5]. For precise DOA estimation, a beam-forming technique, based on hybridization of soft-computing methods is reported in [6]. A complex quaternion LMS algorithm is used in [7] for beam-forming of polarization-sensitive electromagnetic vector-sensor. A comparative study on beam formation using least mean square (LMS) algorithm and recursive least square algorithm (RLS) is reported in [8]. The constrained LMS algorithm is used in adaptive beam forming using perturbation sequences [9]. Report on beam formation in adaptive smart antenna using CSLMS algorithm is relatively less.

In this paper, array synthesis method, Tchebyscheff distribution (TD) for current amplitude distribution in linear antenna array of 16 elements, is used with beam forming CSLMS algorithm. First, CSLMS algorithm is used for beam formation for adaptive smart antenna and then the program is modified to incorporate Tchebyscheff distribution along with CSLMS algorithm which is TDCSLMS. Different values of SLL are considered in Tchebyscheff distribution and then the performances are investigated with respect to beam direction, null direction, beamwidth and side lobe level. In section 2, the basics of constraint stability least mean square (CSLMS) is described. Adaptive beam formation method and results using Tchebyscheff distribution and CSLMS are described in section 3. The discussion on simulated results is included in section 4.

## 2. BEAM-FORMING ALGORITHM

Constrained least mean square algorithm is one of the most commonly used linear-equality-constrained adaptive filtering algorithms**.** Constrained adaptive filtering algorithms are used for applications where a parameter vector need be estimated subject to a set of linear equality constraints. A constrained stability LMS (CSLMS) algorithm for filtering speech sounds, is proposed by minimizing the squared Euclidean norm of the difference weight vector under a stability constraint defined over estimation error [10]. In CSLMS algorithm with adaptively adjusting step size based on error signal is used to improve filtering performance and convergence speed. Adaptive algorithm is used to minimize the error e(n) between desired signal d(n) and array output y(n), as

$$e(n) = d(n) - y(n) \qquad (1)$$

In the CSLMS algorithm, the time-varying step-size is inversely proportional to the squared norm of the difference between two consecutive input vectors. The weight update equation of CSLMS algorithm is [10]

$$w(n+1) = w(n) + \mu \frac{\delta u(n)\delta e^*(n)}{\|\delta u(n)\|^2} \qquad (2)$$

Where $\delta\mathbf{u}(n) = \mathbf{u}(n) - \mathbf{u}(n-1)$ denotes the difference of the input vector; $\delta e(n) = e(n) - e(n-1)$ is the difference of error signal; and the error signal, $e(n) = d(n) - \mathbf{W}^{\mathbf{H}}(n)\mathbf{u}(n)$ ; $d(n)$ is the desired signal, and μ is the step size.

The weight adaptation rule can be made more robust by introducing a factor 'p' and by multiplying the weight increment by a constant step size μ to control the speed of the adaptation. This gives the weight update relation for CSLMS algorithm in its final form as follows [10],

$$w(n+1) = w(n) + \mu \left[ \frac{\delta u(n)\delta e^*(n)}{p + \|\delta u(n)\|^2} \right] \qquad (3)$$

The step size in the CSLMS algorithm affects convergence speed and steady state maladjustment. Since the adaptive algorithm generally has larger error signal at beginning of the computation, and smaller error when it converge, error signal can be used as a reference for the adjustment of step size. That is a larger step size can be applied at the beginning for a faster convergence speed, and a smaller one can be used at the stage of convergence for a smaller maladjustment.

## 3. BEAM FORMATION OF ADAPTIVE SMART ANTENNA

A uniform linear array of inter-element spacing 'd' is shown in figure 1.

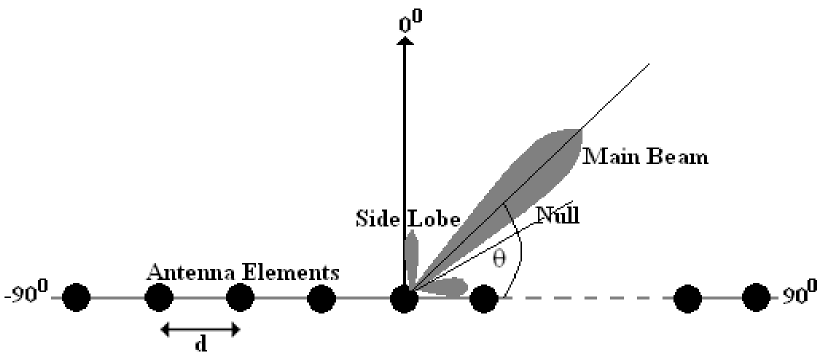


**Figure 1:** Linear Antenna Array Configuration

For a main beam at an angle θ, the array factor is expressed as [11]

$$AF_L = \sum_{n=0}^{N-1} A_n e^{\left(jn\left(\frac{2\pi d}{\lambda}\cos\theta + \alpha\right)\right)} \qquad (4)$$

Where phase factor $\beta=2\pi/\lambda$ and to generate the main beam at wavelength $\lambda$ toward the desired beam direction $\theta^0$ from the broadside direction, the progressive phase shift is

$$\alpha = \frac{-2\pi d}{\lambda} cos\theta \quad (5)$$

Tchebyscheff distribution (TD) for current amplitude [11, 12], fed in antenna, is used for antenna array synthesis to achieve narrowest beam for a given side lobe level. Also it is used to obtain lowest side lobe level for a given beam width. Tchebyscheff distribution, expressed in polynomial form as [11, 12]

$$T_m(x) = \cos(m\cos^{-1} x) \; ; \quad -1 < x < +1$$

$$= \cos(m\cosh^{-1} x) \; ; \quad |x| > +1 \quad (6)$$

$$T_m(x_o) = b \quad (7)$$

It can be calculated [12] by notifying that if, $b = \cosh\rho$ , then

$$x_o = \cosh(\rho / m) \quad (8)$$

Beamwidth is directly related to ‘b’ and ‘ $x_o$ ’ is related to the position of main beam.

In this paper, in adaptive beam formation, array synthesis method Tchebyscheff distribution is used along with beam forming algorithm CSLMS to generate adaptive beam in a particular direction as well as in the direction of predefined null. The cost function is the final array factor for Tchebyscheff array, which is

$$AF = AF_L T_m(x) \quad (9)$$

Normalized array factor is

$$AF_{norm} = \left|\frac{AF}{AF_{max}}\right| \quad (10)$$

Here, $AF_{max}$ is the maximum value of array factor (AF) which is maximum along the direction of main beam. In computer programming, particular directions of main beam and null are given as input for 16 elements linear antenna array. The value of inter-element spacing ‘d’ is 0.5λ. Then in Tchebyscheff distribution different fixed values of side lobe levels (-20 dB, -25 dB, -30 dB) are chosen. In the TDCSLMS algorithm, first the current amplitudes, fed to the antennas, are determined using Tchebyscheff distribution for a particular value of SLL. Then CSLMS algorithm is used to weight update to generate beam and null in particular directions. The normalized array factor obtained using CSLMS for beam direction $10^0$ and null direction $25^0$, beam direction $15^0$ and null direction $22^0$ and beam direction $35^0$ and null direction $45^0$ respectively are plotted in figure 2, figure 3 and figure 4 respectively.

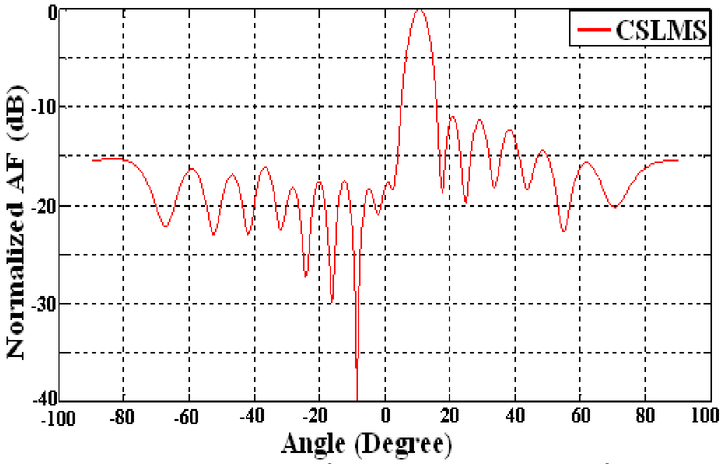


**Figure 2:** Array Pattern for Beam Direction of $10^0$ and Null Direction of $25^0$ Using CSLMS with μ=0.002

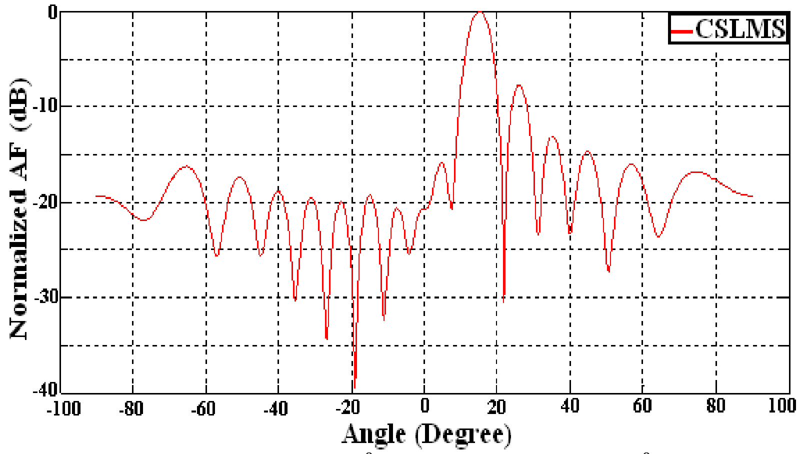


**Figure 3:** Array Pattern for Beam Direction of $15^0$ and Null Direction of $22^0$ Using CSLMS with μ=0.002

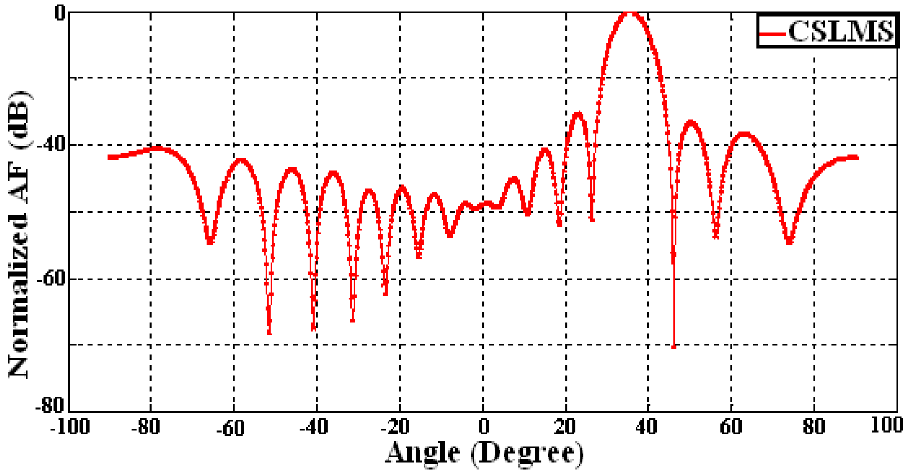


**Figure 4:** Array Pattern for Beam Direction of $35^0$ and Null Direction of $45^0$ Using CSLMS with μ=0.002

The normalized array factor obtained using TDCSLMS for beam direction $10^0$ and null direction $25^0$, beam direction $15^0$ and null direction $22^0$ and beam direction $35^0$ and null direction $45^0$ respectively are plotted in figure 5, figure 6 and figure 7 respectively. In these cases side lobe levels are set at -25 dB in Tchebyscheff distribution.

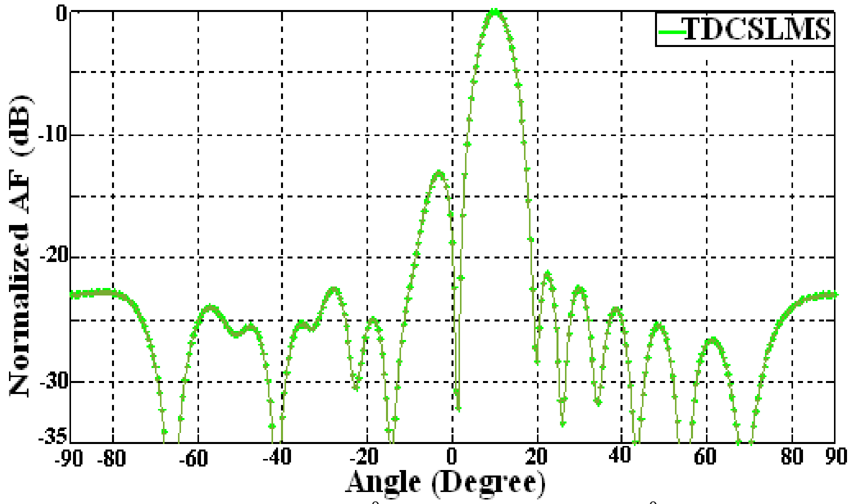


**Figure 5:** Array Pattern for Beam Direction of $10^0$ and Null Direction of $25^0$ Using TDCSLMS with μ=0.004

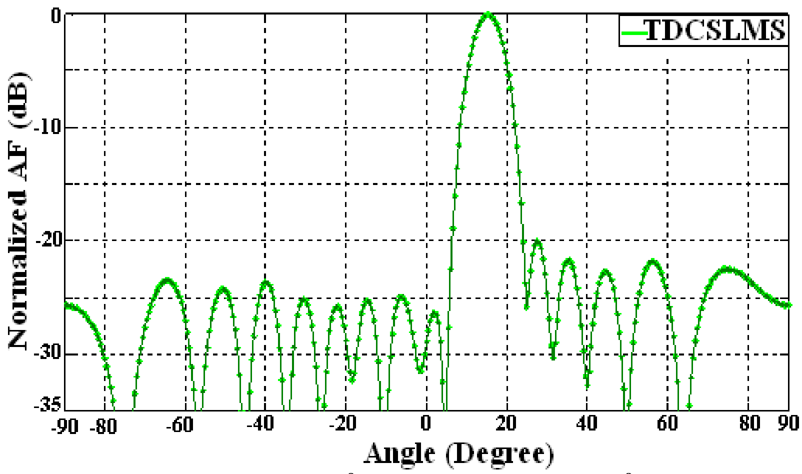


**Figure 6:** Array Pattern for Beam Direction of $15^0$ and Null Direction of $22^0$ Using TDCSLMS with μ=0.003

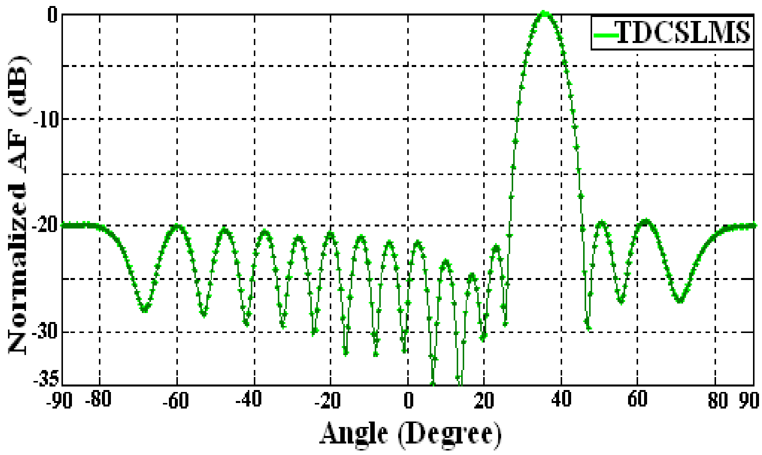


**Figure 7:** Array Pattern for Beam Direction of $35^0$ and Null Direction of $45^0$ Using TDCSLMS with μ=0.002

The normalized array factor obtained using TDCSLMS for beam direction $10^0$ and null direction $25^0$, beam direction $15^0$ and null direction $22^0$ and beam direction $35^0$ and null direction $45^0$ respectively are plotted in figure 8, figure 9 and figure 10 respectively. In these cases side lobe levels are set at -20 dB in Tchebyscheff distribution.

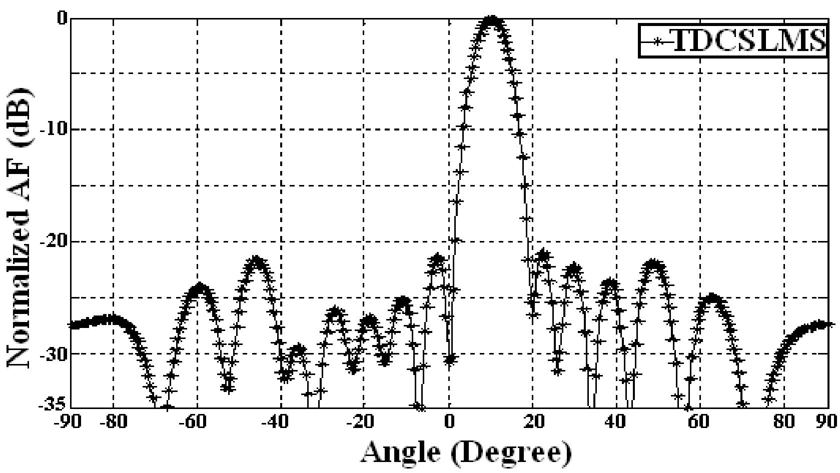


**Figure 8:** Array Pattern for Beam Direction of $10^0$ and Null Direction of $25^0$ Using TDCSLMS with μ=0.003

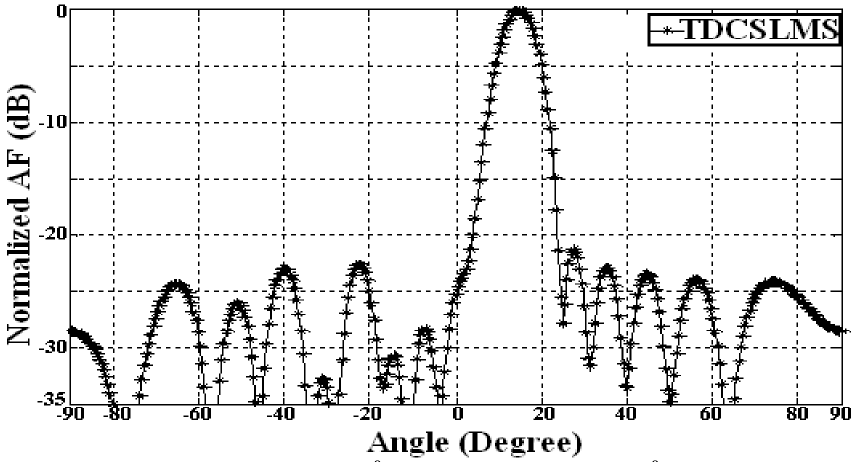


**Figure 9:** Array Pattern for Beam Direction of $15^0$ and Null Direction of $22^0$ Using TDCSLMS with μ=0.003

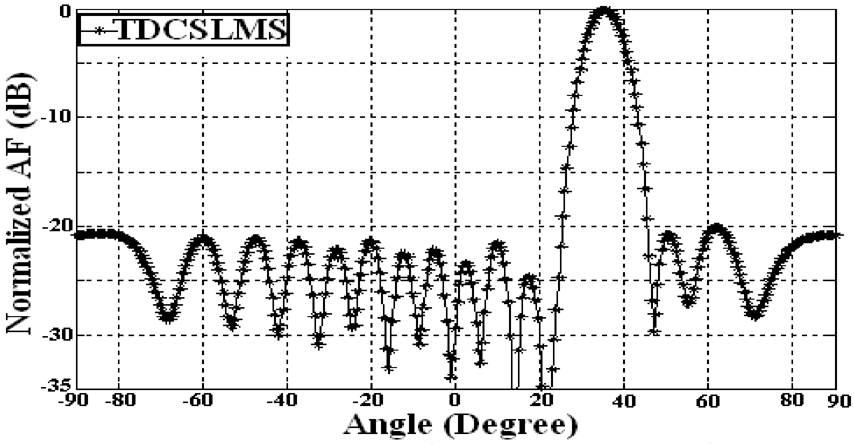


**Figure 10:** Array Pattern for Beam Direction of $35^0$ and Null Direction of $45^0$ Using TDCSLMS with μ=0.003

The normalized array factor obtained using TDCSLMS for beam direction $10^0$ and null direction $25^0$, beam direction $15^0$ and null direction $22^0$ and beam direction $35^0$ and null direction $45^0$ respectively are plotted in figure 11, figure 12 and figure 13 respectively. In these cases side lobe levels are set at -30 dB in Tchebyscheff distribution.

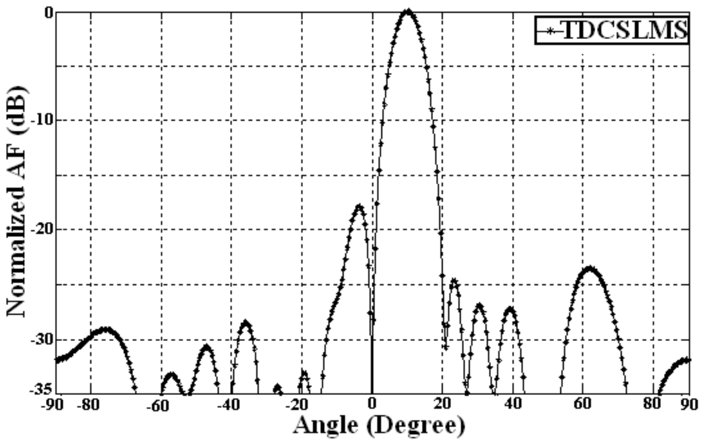


**Figure 11:** Array Pattern for Beam Direction of $10^0$ and Null Direction of $25^0$ Using TDCSLMS with μ=0.003

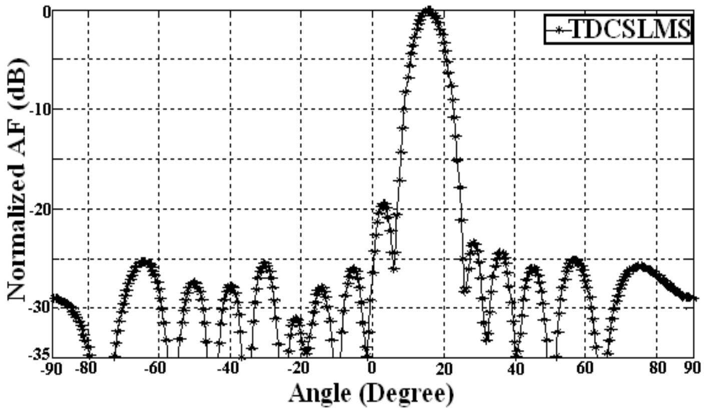


**Figure 12:** Array Pattern for Beam Direction of $15^0$ and Null Direction of $22^0$ Using TDCSLMS with μ=0.003

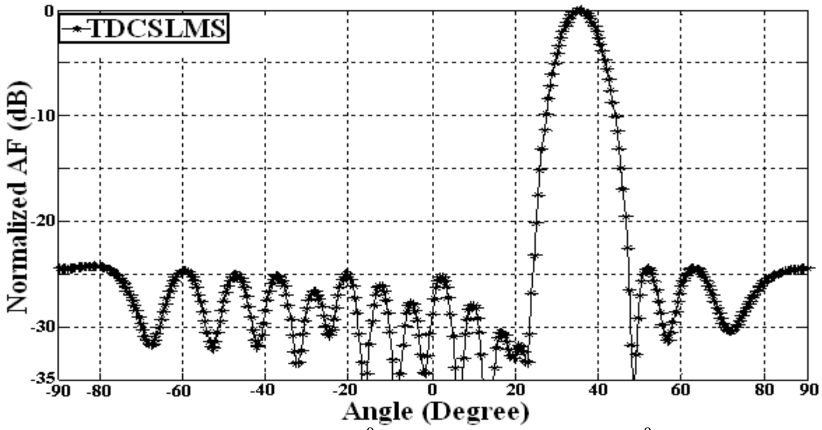


**Figure 13:** Array Pattern for Beam Direction of $35^0$ and Null Direction of $45^0$ Using TDCSLMS with μ=0.003

The summary of results with respect to null direction, null-to-null beamwidth (BW) and side lobe level (SLL) are tabulated in table 1for all the cases considered in this paper. In all the algorithms, desired main beam directions achieved perfectly, whereas, in some cases there is small shift of null directions from the desired value.

**Table 1:** Performances of Beam-forming Algorithms CSLMS and TDCSLMS

| ***Desired* beam direction, null direction** | **CSLMS** | | | **TDCSLMS (In TD SLL = -20 dB)** | | | **TDCSLMS (In TD SLL = -25 dB)** | | | **TDCSLMS (In TD SLL = -30 dB)** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Null Direction | BW | SLL | Null Direction | BW | SLL | Null Direction | BW | SLL | Null Direction | BW | SLL |
| $10^0$, $25^0$ | $25^0$ | $14^0$ | -11dB | $26^0$ | $20^0$ | -22dB | $26^0$ | $19^0$ | -13dB | $26^0$ | $20^0$ | -18dB |
| $15^0$, $22^0$ | $23^0$ | $15^0$ | -11dB | $24^0$ | $22^0$ | -21dB | $24^0$ | $19^0$ | -20dB | $25^0$ | $20^0$ | -19dB |
| $35^0$, $45^0$ | $46^0$ | $19^0$ | -15dB | $47^0$ | $23^0$ | -20dB | $47^0$ | $21^0$ | -19dB | $47^0$ | $25^0$ | -24dB |

## 4. DISCUSSIONS AND CONCLUSIONS

A new method of adaptive beam formation for smart antenna using Tchebyscheff distribution and CSLMS algorithm is presented here. Lower side lobe level is achieved using this proposed method for all the cases compared to using only CSLMS algorithm. Number of iterations in each computation is 100. Simulations are done using large number of step-size values in CSLMS algorithm. The step-size values (μ) in all the cases mentioned from figure 2 –

figure 13 are the values for which best results (with respect to beam direction, null direction, SLL) are found. In array synthesis using Tchebyscheff distribution (TD), the number of nulls (m) is decided by the polynomial $T_m(x)$. But in adaptive beam formation when TD is used with CSLMS algorithm, the number of nulls may not be same as expected using TD only. In all the cases of TDCSLMS, the directions of main beams are achieved accurately. In beam formation using TDCSLMS, in some cases the direction of nulls are shifted slightly from the desired direction, as mentioned in table 1. In those cases sharp nulls are not produced at the desired null directions but the levels of radiation in desired null directions are far below the effective levels.

## 5. REFERENCES

[1] T. K. Sarkar, M. C. Wicks, M. Salazar-Palma, Robert J. Bonneau, Smart Antennas, Wiley-IEEE Press, 2003.
[2] F. Gross, Smart Antenna for Wireless Communication, McGraw-Hill, 2005.
[3] L. C. Godara, "Application of antenna arrays to mobile communications, Part II: beam-forming and direction-of-arrival considerations", Proceedings of the IEEE, vol. 85, no. 8, pp. 1195–1245, Aug. 1997.
[4] S. Bellofiore, C. A. Balanis, J. Foutz, A. S. Spanias, "Smart-antenna systems for mobile communication network", part 1, overview and antenna design", IEEE Antennas and Propagation Magazine, vol. 44, no.3, pp. 145- 154 June 2002.
[5] M. Mouhamadou, P. Vaudon, M. Rammal, "Smart antenna array patterns synthesis: null steering and multi-user beamforming by phase control," Progress In Electromagnetics Research (PIER), vol. 60, pp. 95-106, 2006.
[6] T. S. Ghouse Basha, P. V. Sridevi, M. N. Giri Prasad, "Beam forming in smart antenna with precise direction of arrival estimation using MUSIC algorithm", Wireless Personal Communications, vol. 71, issue 2, pp. 1353-1364, July 2013.
[7] J-W Tao, W-X Chang, "Adaptive beamforming based on complex quaternion processes", Mathematical Problems in Engineering, Hindawi, vol. 2014, pp 1-10, June 2014.
[8] A. Senapati and J. S. Roy, "Beam-forming and beam-shaping in smart antenna-a comparative study between least mean square and recursive least square algorithms", International Journal of Microwave and Optical Technology (IJMOT), vol. 10, no. 4, pp. 232-239, July2015.
[9] L. C. Godara, A. Cantoni, "Analysis of constrained LMS algorithm with application to adaptive beamforming using perturbation sequences", IEEE Transaction on Antennas and Propagation, vol. 34, no. 3, pp. 1804-1807, March 1986.
[10] G. Somg, G. Liu, W. Liu, Z. Long, S. Wang, "A modified constraint stability-least mean square algorithm and its application in chaos communication", In Proceedings of 5th International Congress on Image and Signal Processing, Sichuan, China, Oct. 16-18, 2012, IEEE Xplore, pp. 368-379, 2012.
[11] C. A. Balanis, Antenna Theory – Analysis and Design, 3rd Ed., Wiley, 2005.
[12] E. C. Jordan, K. G. Balmain, "Electromagnetic Waves and Radiating Systems", 2nd Ed., Prentice Hall of India, New Delhi, 2009.