ISSN (ONLINE): 2395-695X
ISSN (PRINT): 2395-695X

International Journal of Advanced Research in Basic Engineering Sciences and Technology (IJARBEST)
Vol. 2, Issue 12, December 2016

Simulation of an Adaptive Digital Beamformer using Matlab

Anila Jose
Assistant Professor, ECE Department, FISAT, Angamaly, India

Abstract— **Beam forming is the process of combining the weighted signals received on an array of sensors to improve the directionality. Adaptive beamforming is the ability of the beamformer to receive the signal only from the desired direction and to reject all other signals from undesired directions. The weight vector for the adaptive beamformer continuously changes based on some adaptive algorithm. Therefore, adaptive digital beam formers can point the antenna to the signal direction without changing the physical architecture of the array antenna. The beam pointing direction can be varied electronically with this technique. This paper focuses on Least Mean Square (LMS) adaptive algorithm.**

Index Terms— **Beamformer, Digital Beamformer (DBF) Receiver, Direction of Arrival (DoA), Least Mean Square (LMS) algorithm**

I. INTRODUCTION

An antenna array is a group of similar antennas whose signals are combined in such a way that the overall radiation pattern is reinforced in certain desired direction and suppressed in other undesired directions [1]. When a radiation beam falls on an antenna array at an angle θ, the signal gets induced in each antenna element at different times due to the spacing between the array elements. This result in phase difference in the signals induced at each antenna element. Therefore, amplitude scaling and phase coherency has to be maintained for the constructive addition of the signals induced in each antenna so that the high gain output is obtained at the antenna array [2-3]. This is done by multiplying the received signal on each antenna element with the weight vector.

There are different stages for the digital beam former receiver, namely RF translation stage, digital down conversion stage, complex weight multiplication stage, summation stage. RF translation stage converts high frequency received signal to the intermediate frequency range prior to the digitization [4]. Digitization is done by analog to digital converters in the RF translation stage. Phase coherency and amplitude scaling is performed by multiplying the array element signal with the complex weight in the complex weight multiplication stage. These processed signals are finally added to get highly directional beam in the desired direction. Digital beam forming is a beam forming technique in which amplitude scaling, phase compensation, summations are done digitally [5].

There are two types of beam formers namely, conventional beamformer and adaptive beamformer. Conventional beamformer uses fixed weight vector whereas adaptive beamformer uses a weight vector which adaptively changes with the direction of arrival of desired radiation. It uses some adaptive algorithms to update the weight vector and the optimum weight is used to obtain the beamformer output.

II. THEORETICAL BACKGROUND

An antenna is an electrical transducer which converts radio signals into electrical signals and vice versa. It is usually associated with a radio transmitter or radio receiver. Antennas are used with every radio systems such as television broadcasting, satellite communication, radio broadcasting, radar, wireless communication systems.

Two or more similar antennas connected together to improve the antenna performance is known as antenna array. These connected antennas works as a single antenna. Theory of antenna array is applicable to both transmitter and receiver side. Each antenna in antenna array is known as array element. Directional gain of the antenna can be improved with the use of antenna array. An array with N antenna elements can improve the directional gain by a factor N. Another advantage of using antenna array is that array's radiation pattern (array pattern) can be varied without changing its physical dimension. The performance level of the antenna array increases with the increase in number of array elements. But the drawback of this antenna array system is the increased cost, design complexity, size etc.

Consider an antenna array with N elements spaced by'd' distance apart along an axis as shown in the Fig.1. A plane wave is assumed to be incident on array elements at an angle θ to the normal direction. The radiation falls at each antenna element at different time due to the spacing between the elements. This time delay results in phase shift in the signal induced at each antenna element.

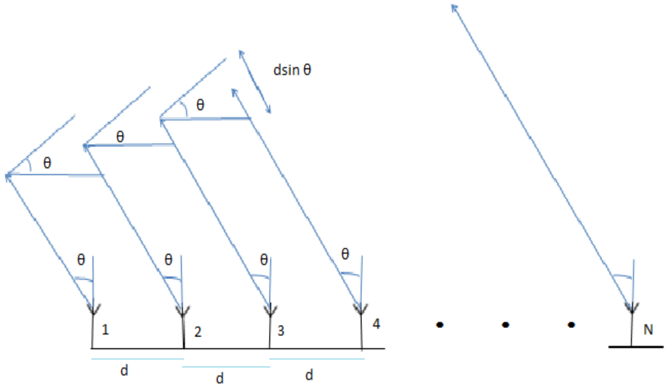


Fig 1.Antenna array.

Phase shift in the nth antenna element is given by,

$$\varphi_n = (n-1)(kd\sin\theta + \beta) \tag{1}$$

where k is the wave number which is given by

$$k = 2\pi / \lambda \tag{2}$$

λ is the wavelength of the incident radiation, β is the progressive phase difference and d is the spacing between the antenna elements [6].

Steering vector for the four element antenna array is given by,

$$[1 \quad e^{j\varphi_2} \quad e^{j\varphi_3} \quad e^{j\varphi_4}] \tag{3}$$

A. Beamforming

Beamforming is the technique of combining the signals induced in each antenna element of antenna array. Separate phase controls and amplitude controls are provided at the antenna elements to cancel out the effect of phase difference and amplitude variation in the induced signal in each element. Fig. 2 shows the block diagram for beamforming. K number of antennas are shown in the figure and $X_1(n)$, $X_2(n)$….$X_K(n)$ are the signals induced on each antenna element. These signals are multiplied with weight values W_1, W_2….W_K and the weighted signals are added up to obtain the beamformer output y(n).

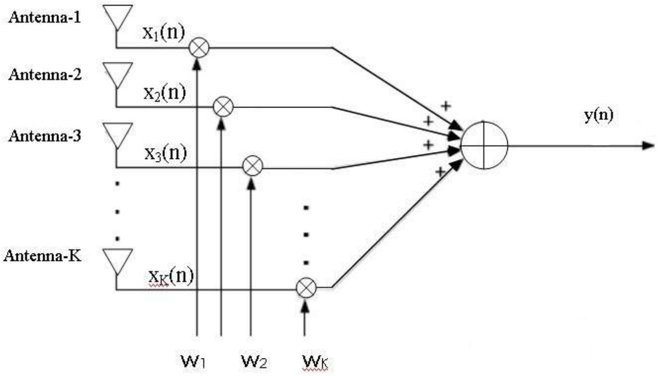


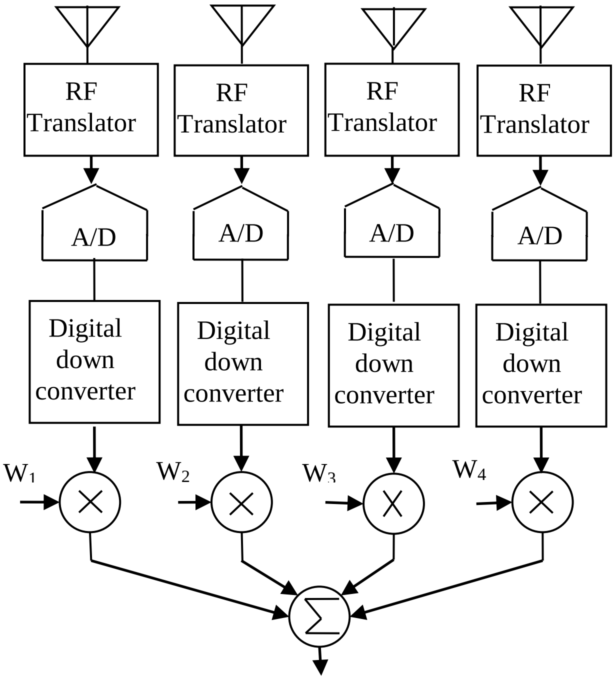
Fig 2.Beamforming.

For a four element adaptive beamformer, weight multiplication is given by,

$$[1 \quad e^{j\varphi_2} \quad e^{j\varphi_3} \quad e^{j\varphi_4}][w_1 \quad w_2 \quad w_3 \quad w_4] \tag{4}$$

The weight vector for the adaptive beamformer can be calculated by using different algorithms. Least mean square (LMS) algorithm is used in this project work. Phase shift in each antenna element is compensated by the complex weight multiplication and thereby phase coherency is achieved.

Digital beamformer architecture consists of many digital receivers associated with each antenna element of the array. In digital beamforming, operations such as phase compensation, amplitude scaling and the summation are done digitally. The received signal from each antenna is digitized using analog to digital converters. RF translation is performed prior to the A/D converters. Digital down converters (DDC) are used to generate in phase and quadrature components of the signal. Each DDC baseband output is multiplied by the complex weight for its antenna element, and the results are summed to produce one baseband signal with directional properties. A demodulator would then follow to recover the information from the received signal.



Output to demodulator

Fig 3.Digital Beamformer.

B. Least Mean Square Algorithm

Least mean square (LMS) adaptive algorithm is widely used in signal processing applications. It is a gradient based method of steepest descent which makes use of the estimate of gradient vector from the available data. It incorporates an iterative procedure to update the weight vector in the direction of negative gradient vector so that the optimum weight vector can be calculated. This algorithm minimizes the mean square error value. It is relatively simple and does not require any matrix inversion calculation and correlation function calculation [7].

Gradient based algorithms are based on a quadratic performance surface which is a function of array weights. The performance function is in the shape of an elliptic parabola

with only one minimum. The aim of these algorithms is to find the minimum point on the performance surface. This gives the optimum weight value with minimum mean square error. The error signal is defined as the difference between the desired signal and the beamformer output. LMS algorithm is employed to minimize the error between the desired signal and beamformer output [8].
The output of the filter is given by,

$$y(n) = w^H x(n) \tag{5}$$

The error signal is defined as,

$$e(n) = d^*(n) - y(n) \tag{6}$$

Weight updating equation is obtained as,

$$w(n+1) = w(n) + \mu e^*(n)x(n) \tag{7}$$

Where μ is the step size parameter which controls the convergence characteristics of LMS algorithm.

$$0 < \mu < \frac{1}{\lambda_{\max}} \tag{8}$$

$\lambda_{\max}$ is the largest eigen value of the autocorrelation matrix (R) of the input signal x(n) and d(n) is the desired signal.

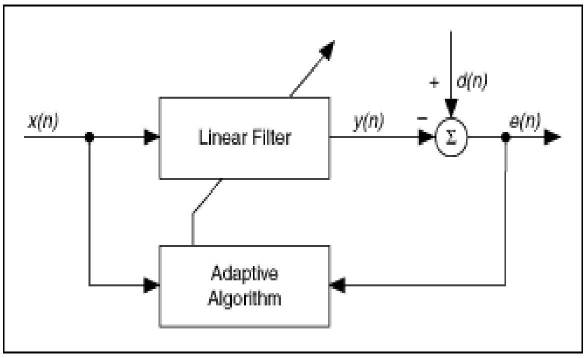


Fig 4.General block diagram.

The convergence of the algorithm is inversely proportional to the Eigen spread of the autocorrelation matrix R. The Eigen value spread of the autocorrelation matrix is defined as the ratio of largest Eigen value to the smallest Eigen value. The convergence rate of the algorithm is slow when the Eigen values of R are widespread [9].

If the μ value chosen is very small, then the algorithm converges very slowly. ie, the time taken to reach the optimum condition is large. Convergence rate can be improved by choosing μ a higher value but may be less stable.

C. LMS Algorithm in Digital Beamformer receiver

The weight vector for the antenna array is initialized as zero and in training phase, it gets updated iteratively to obtain the optimum weight. Fig.5 shows the general block diagram for the adaptive beamformer. The signals received by these antenna elements are multiplied with the weight vector. These weighted signals are added to obtain the beamformer output [10].

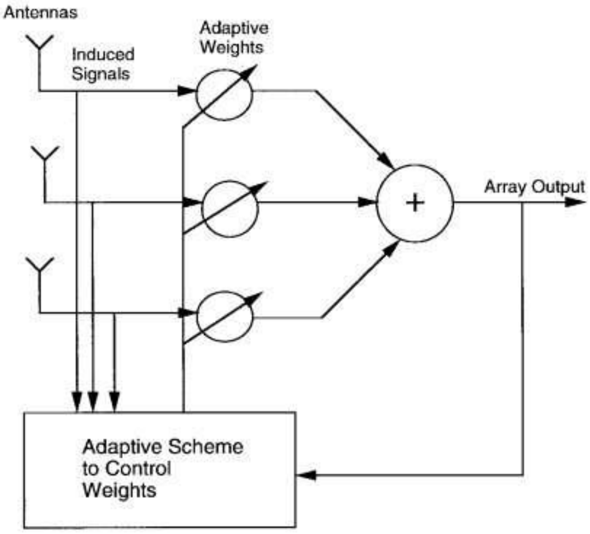


Fig 5.Adaptive Beamformer.

III. RESULTS

The radiation beam from different desired direction is allowed to fall on the antenna array and in each case, radiation pattern is plotted.

Fig. 6 shows the desired signal with direction of arrival 60 degrees. Fig. 7 shows the phase shifted noisy signal received on each antenna elements with direction of arrival 60 degrees.

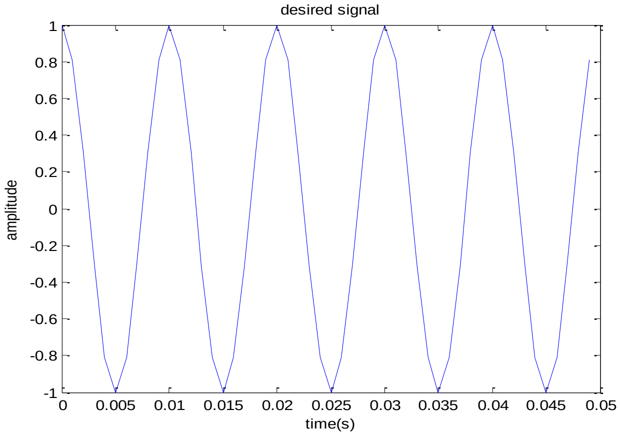


Fig 6.Matlab simulated desired signal.

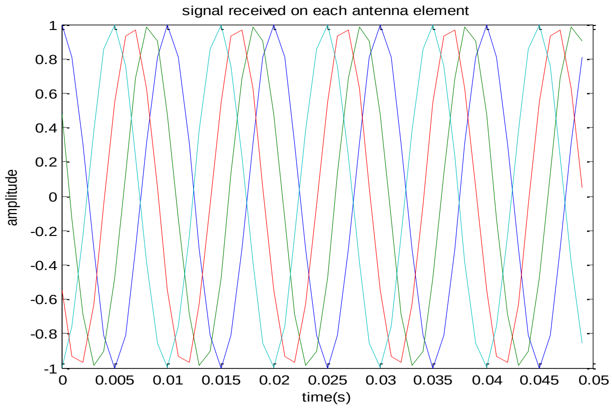


Fig 7. Phase shifted signal received on each antenna element with desired direction 60 degrees.

Fig. 8 shows the weight updating waveform of each antenna element. The weight vector is initialized as zero and it gets updated iteratively to get the optimum value according to the LMS algorithm.

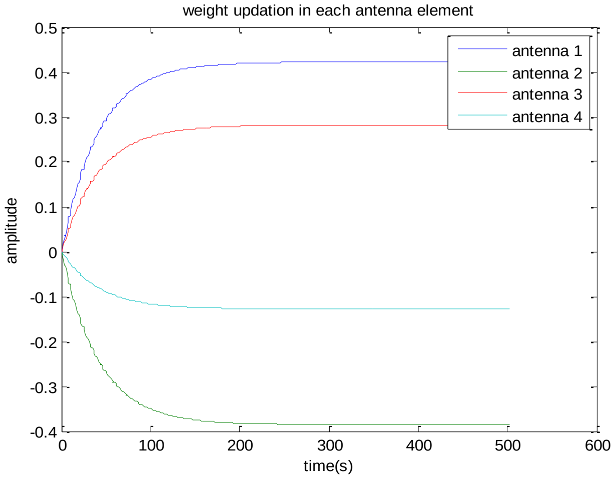


Fig 8. Weight updating waveform for each antenna element

Fig.9 shows the error signal for the LMS algorithm. Initially, it is at maximum value and reduces to zero as number of iteration increases.

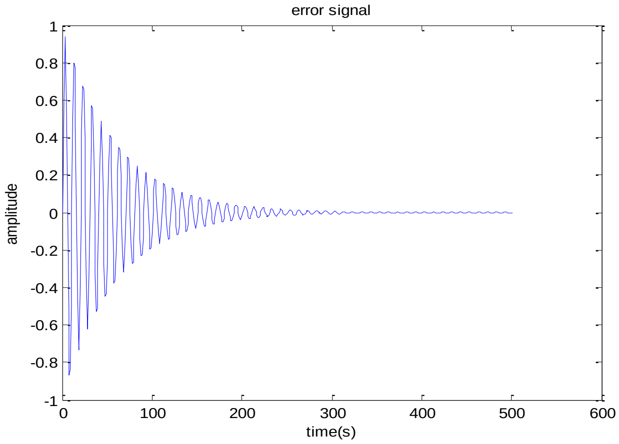


Fig 9. Error signal for the LMS algorithm

With the LMS algorithm, optimum weights are calculated for the desired direction 60 degrees. Now, the beamformer is trained to give maximum output only for 60 degrees and it gives reduced signal strength in all other direction. Fig. 10 shows the beamformer output with desired direction 60 degrees and the direction of arrival also 60 degrees. Here, the desired signal and the beamformer output coincide.

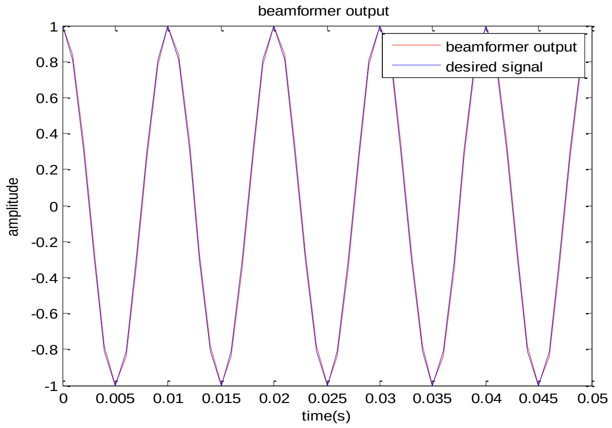


Fig 10. Beamformer output with desired direction 60 degrees and direction of arrival 60 degrees

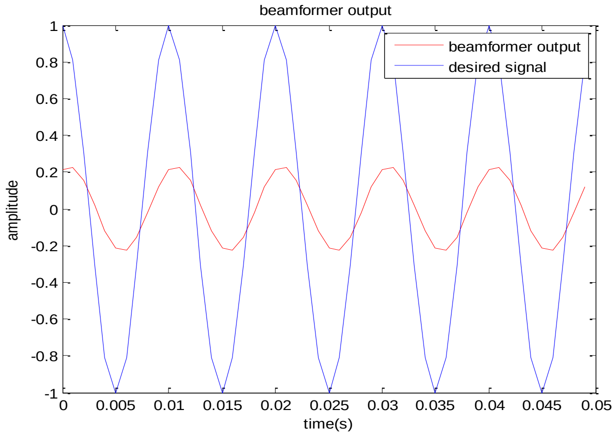


Fig 11. Beamformer output with desired direction 60 degrees and direction of arrival 20 degrees

Beamformer for different desired direction say,60 degrees, 0 degrees, -50 degrees are simulated and the signal strength is measured for different direction of arrival (-90 degrees to +90 degrees) and radiation patterns are plotted.

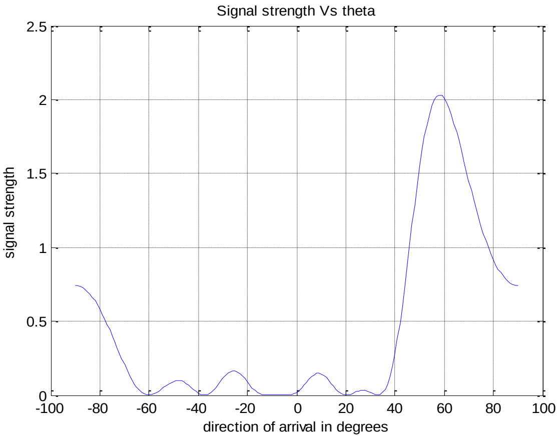


Fig 12. Signal strength versus direction of arrival plot for simulated output for source angle at 60 degrees

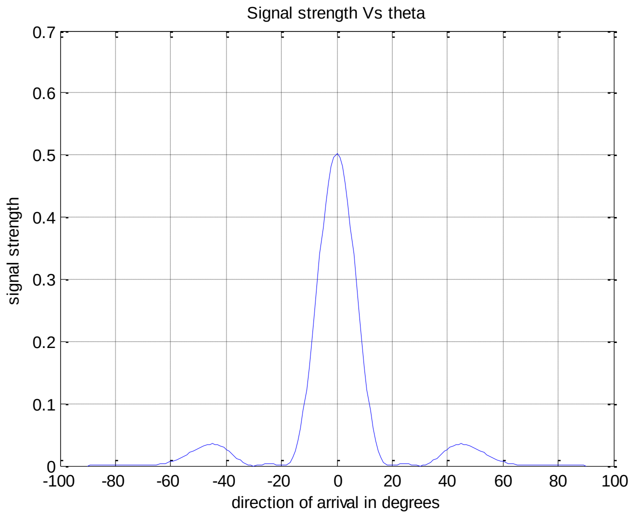


Fig 13. Signal strength versus direction of arrival plot for simulated output for source angle at 0 degrees

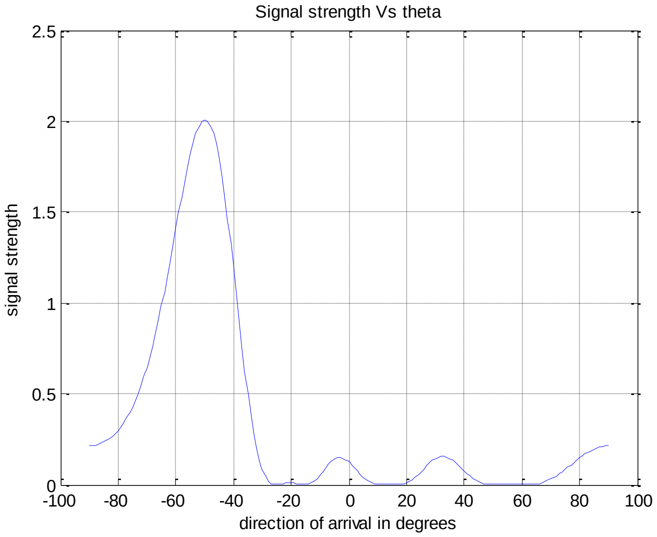


Fig 14. Signal strength versus direction of arrival plot for simulated output for source angle at -50 degrees

ACKNOWLEDGMENT

It is my privilege to remember here the grace of GOD ALMIGHTY and all those people who have contributed directly or indirectly in the successful execution of my project. I would like to express my gratitude to the Electronics and Communication department, Federal Institute of Science and Technology, Kerala, India for providing me with all the required facilities without which the project would not have been possible.

REFERENCES

[1] Balanis C.A., *Antenna Theory: Analysis and Design*, Second Edition, John Wiley & Sons, New York, 1997.
[2] K.D Prasad, *Antenna Wave Propagation*, Satya Prakashan, New Delhi,1995
[3] P. Goel and K. J. Vinoy," A low-cost phased array antenna integrated with phase shifters cofabricated on the laminate", in Progress In Electromagnetics Research B, Vol. 30,pp. 255–277, 2011
[4] Taco Kluwer, "Development of a test-bed for smart antennas, using digital beamforming", December 2000-August 2001
[5] Juan A. Torres-Rosario, "Implementation Of A Phased Array Antenna Using Digital Beamforming", Master Of Sciences,In Electrical Engineering, University Of Puerto Rico, Mayagüez Campus, 2005
[6] Toby Haynes ,A Primer on Digital Beamforming Spectrum Signal Processing March 26, 1998
[7] Least Mean Square algorithm Ch_6lms.pdf K.K.Shetty,2004.
[8] B.Widrow and S.D.Stearns, *Adaptive Signal Processing,* Prentice-Hall, 1985
[9] S. Haykin, "Adaptive Filter Theory", Fourth Edition, Prentice Hall, Upper Saddle River, N.J., 2002.
[10] D.M.M.Rahaman., Md.M.Hossair, "Least Mean Square (LMS) For Smart Antenna", Universal Journal of Communications and Network",pp-16-21,2013

Author Biography

Anila Jose received the BTech degree in Electronics and Communication Engineering from Mahatma Gandhi University, Kerala, India, in 2013. She obtained her post graduation in Communication Engineering, Federal Institute of Science and Technology (FISAT), Kerala, India. Her current research area includes communication.