JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Performance Evaluation of Smart Patch Array Feed Parabolic Reflector using Conjugate Gradient Method

Sheetal Bawane[1] and D.K.Panda[2*]
[1]Department of Electronics & Communication Engineering, Medi-Caps University Indore, (M. P.) India

Abstract— The design of a patch antenna array feed for high frequency applications is the subject of this study. To improve directivity and radiation properties, the proposed array feed is fed to the parabolic reflector. The adaptive Conjugate Gradient Method (CGM) adaptive beamforming approach concentrates the radiation power even further in the intended direction. It's also been used to cancel out interference in the appropriate direction. For C-band applications such as satellite communication, the design is presented as an alternate feed antenna to the traditional horn-based feed network. An 8x1 linear rectangular patch antenna array framework with a broadside radiation pattern is used in the suggested design. The F/D ratio of the parabolic reflector fed by the array is 0.36, equal to 1400 aperture illumination. Simulation analysis is used to verify the effectiveness of the suggested design.

Keywords*-Microstrip patch, Adaptive antennas, Conjugate Gradient Method (CGM), parabolic reflector, beamforming, antenna arrays, smart antenna.*

I. Introduction

The exponential advancement of cellular communication technology over the previous decade has shifted the entire wireless communication paradigm. The ability to store, analyze, and communicate vast amounts of data has increased dramatically in tandem with advancements in electrical circuits and gadgets. In terms of size, cost, power, and speed, large scale integration has introduced a new dimension to the design features of electronic systems. Researchers in practically every discipline of engineering have effectively used these potential benefits to achieve new heights of development and execution [1].

When it comes to high-speed wireless communication, spectral efficiency, and capacity, antenna design is critical. The total performance of the communication system is determined by the antenna's capacity to transmit and receive high bandwidth signals in a given direction with the necessary strength. The dependence of antenna physical dimensions on frequency of operation and radiation characteristics poses a significant challenge to communication system researchers and engineers. Many scholars have worked on the subject of efficient and prospective antenna designs during the last few decades. Antennas of various shapes and designs have been investigated for various uses [2-5].

Due to its better spectrum characteristics, the parabolic reflector antenna has found a significant place in high frequency communication. The antenna's parabolic framing produces a crisp beam of radiation, which improves signal directivity and beamwidth. Because of these characteristics, it is an excellent candidate for a point-to-point communication system. The parabolic reflector has emerged as the preferred choice for sky wave propagation due to its simple structure, high gain, and directivity [6]. The signal's power and strength have been improved even more by using an antenna array network to feed the base antenna. It also aids in the distribution of antenna apertures and consistent illumination. Because of its strong directivity, horn antennas have been utilized as the feed network to parabolic reflectors for demanding applications such as satellite communication for decades. However, the weight and dimensions of this design have made satellite communication difficult. The distribution of power to the antenna elements, on the other hand, has proven to be a significant difficulty for the researchers.

The smart adaptive antenna system has taken use of the capability of improving the antenna array performance even more by modifying the power distribution to the antenna elements adaptively. The spectrum efficiency is significantly improved by iteratively modifying the weight factors of each antenna element. Beamforming is the process of manipulating the shape of the radiation pattern in an antenna array system by manipulating the weights over the spatial domain. By setting the weights with respect to time while maximizing the signal to noise ratio (SNR) and array output in beamforming, the required signals are separated from the interfering signal [7-9].

This research provides a patch antenna array feed for parabolic reflector that reduces the weights and dimensions of traditional satellite communication systems that utilize horn feed reflectors. By adjusting the power distribution among the antenna elements, the performance was further improved utilizing the adaptive beamforming technique over the patch array feed. The mathematical structure of the suggested array feed reflector is the major contribution of the proposed design. The paper's other addition is adaptive tuning rules based on Conjugate Gradient Method adaptive beamforming algorithms, which are superior to traditional adaptive antennas.

The remainder of the paper is structured as follows: Section II provides a thorough review of the literature on various antenna frameworks in order to deduce the reason for the current study. The mathematical structure of a patch antenna array and a parabolic reflector is discussed in Section III. In section IV, a proposed smart antenna-based adaptive method for the patch antenna array feed reflector is provided. In part V, a simulation study of the suggested technique is offered to test its usefulness, and section VI concludes the paper.

II. Literature Survey

Many researchers have looked at the subject of improving radiation properties using various ways depending on the application's needs. In order to attain the greatest possible performance, many dimensions and methods have been given in the literature. Although the basic design components of antenna structure and their dimensional analysis are well-established, researchers have lately attempted to personalize antenna characteristics using adaptive algorithms. The preliminary design aspects of adaptive antenna array were presented by Kamboj and Dahiya [10]. They looked at how adaptive antennas work in satellite communication applications. The authors investigate the self-steering capability of an array design based on the linear adaptive algorithm LMS (Least mean square). To follow the satellite, the number of antenna elements and beam steering angles are changed. Michishita et al.[11] extended the work in their paper. By analysing the respective excitation coefficients, they performed radiation synthesis to achieve a uniform aperture distribution for the antenna array.

The work on smart antennas employing beamforming and the direction of arrival algorithm was proposed by Khalaf and Rahman [12]. The linear and nonlinear beamforming algorithms for antenna design were described by Panda and Shaik [13]. They've suggested a technique that uses a smart antenna to follow a person while also reducing interference. In the study, the linear least mean square (LMS) and decision feedback equalizer based least mean square (DFE-LMS) algorithms were evaluated.

Srar et al.[14] focused on the evaluation of the radiation properties of adaptive smart antenna design to parabolic reflectors. To improve network performance, Bellofiore et al. [15] added beamforming to the Mobile Adhoc Network (MANET). On the basis of convergence rate, speed, computation complexity, and singularity, Saxena and Kothari [16] analyzed various adaptive algorithms for antenna array design. LMS, CMA, LS-CMA, and RLS are the algorithms studied in this work. The importance of power orientation in the adaptive weight calculation for smart antennas was underlined by Rao and Sharma[17]. The study shows how to use maximum power in the desired direction and interference to change the coefficients. To take use of the universal implementation aspects, the design was expanded to Linear array, Circular array, and Planar array. For several adaptive smart antenna techniques, Banerjee and Dwivedi [18] investigated the effect of signal to interference noise ratio. In their paper, they cover various adaptive strategies such as the constant modulus algorithm (CMA), particle swarm optimization (PSO), and non-blind least mean square (LMS).

For systems with slow noise magnitude variation, Cho et al. [19] suggested a modified NLMS algorithm. The noise information was used by the author to speed up the learning process. Convex hybridization has been offered as a way to improve the smart algorithm's performance. C. Jethva and R. Karandikar [20] further on the research of these hybrid algorithms and compared them.

Over the last decade, academics have developed and exploited a variety of adaptive methods to improve antenna performance. However, implementing an adaptive antenna feed method to take advantage of radiation characteristics could bring a new dimension to antenna design..

III. System Preliminaries

A) Single patch antenna array element

Microstrip antennas have attracted a lot of attention in recent years in sensitive applications due to their light weight and small size. Microstrip antennas are also known for their inexpensive cost, ability to be combined on compact printed circuit boards with processing circuitry, and efficient radiation properties. A rectangular patch antenna has a dielectric substrate with a radiating patch on one side and a grounding metal layer attached to the opposing side. Copper or gold is frequently used as a conductor. It has a narrowband wide-beam radiation and is made utilizing the photo-etching technique. Figure 1 depicts the usual structure of a rectangular microstrip antenna. The design of a microstrip antenna is influenced by a number of factors. The following are the key equations that regulate the size of a microstrip rectangular antenna [21]:

Actual length (L) of the path element is given by

$$L = \frac{\lambda}{2\sqrt{\varepsilon_r}} \quad (1)$$

Effective relative permittivity (ε_{reff}) is calculated as

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{\frac{1}{2}} \quad (2)$$

and the effective length is given by

$$L_{eff} = \frac{c}{2 f_0 \sqrt{\varepsilon_{reff}}} \quad (3)$$

The extension length (ΔL) because of the fringing filed is presented as

$$\Delta L = 0.412h \frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \quad (4)$$

where λ represents the wavelength of operation, ε_r is the relative permittivity, h is the height of path, W is the width of the path, f_0 is the frequency of operation and c is the capacitance.

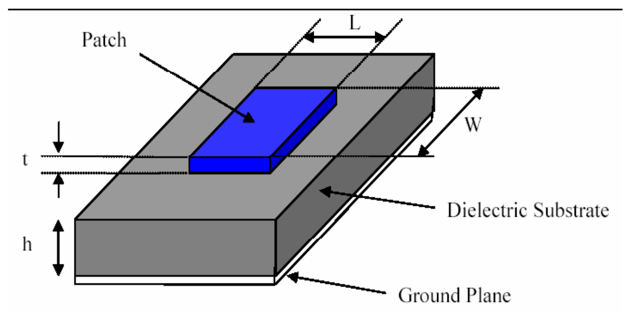

Fig. 1. Rectangular microstrip antenna element

B) Patch Antenna Array Feed

The horn antenna has traditionally provided the feed network for the parabolic reflector. However, the horn antenna's higher size and weight make it difficult to install the feed network in dimension-sensitive applications. A well-designed patch antenna array feed network could successfully tackle this problem, but it must strike a balance between illumination loss and spillover loss to get the required results. The usual method of achieving this tradeoff is to have illumination energy 10 dB reduced at the reflector dish's edge. In addition, the radiation pattern should be similar to or better than that of conventional feed networks, with a beamwidth of up to -10dB. The patch's shape is kept simple by using an 8x1 linear array with a broadside radiation pattern [22]. Figure 2 depicts the appropriate setup.

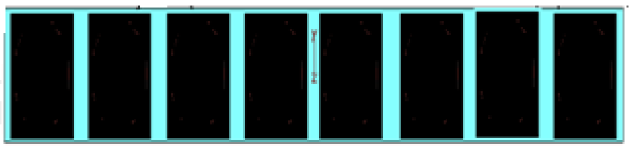

Fig. 2. 8x1 patch antenna array feed (Top View)

The array is designed for a frequency range of 6 GHz, with wavelengths of 5.0 cm and distances between elements of 0.67cm or 0.133 λ. The design was created using the assumptions that the elements are equidistant, evenly phased, and activated by a uniform signal amplitude.

C) Parabolic Reflector

The F/D ratio, which is a crucial characteristic for any application, is used to select the parabolic reflector used in this study. It has been taken as 0.36 in this case, which is similar to the ratio used in most commercial microwave applications [23]. Figure 3 depicts the usual geometric architecture of a parabolic reflector.

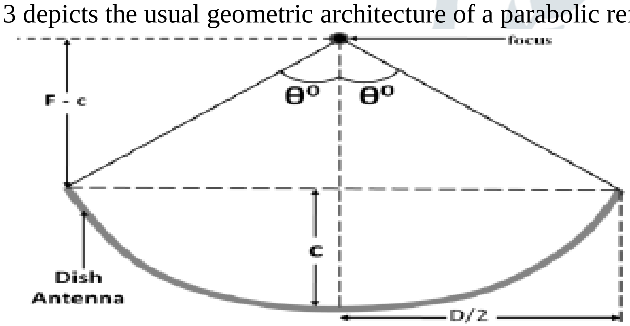

Fig. 3. Basic parabolic antenna geometry

The geometric calculations of the parabolic antenna show that the focal distance (F) can be written as

$$F = \frac{D^2}{16C} \qquad (5)$$

where D is the is the diameter of the dish and C is the depth of parabola at the centre. Also considering

$\tan\theta = \left[\frac{\left(D/2\right)}{F - C}\right]$, we can deduce the aperture illumination as

$$\text{Aperture Illumination} = 2\tan^{-1}\left[\frac{8\left(F/D\right)}{16\left(F/D\right)^2 - 1}\right] \cong 140^0 \qquad (6)$$

IV. Proposed Smart Patch array feed Design

The application of smart antenna principles for the patch antenna array feed network for the parabolic reflector is presented in this study in order to achieve higher radiation performance over the standard horn based antenna. The excitation level and phases of the array elements of a smart antenna can be changed to produce the required radiation properties in a specific direction. It operates on the adaptive filtering concept and adjusts the weights until the desired radiation pattern is attained. The difference between the actual and desired radiation is the parameter utilized for tuning. Beamforming is the process of shaping the radiation pattern with a smart antenna. Figure 4 depicts the beamforming process using adaptive algorithms.

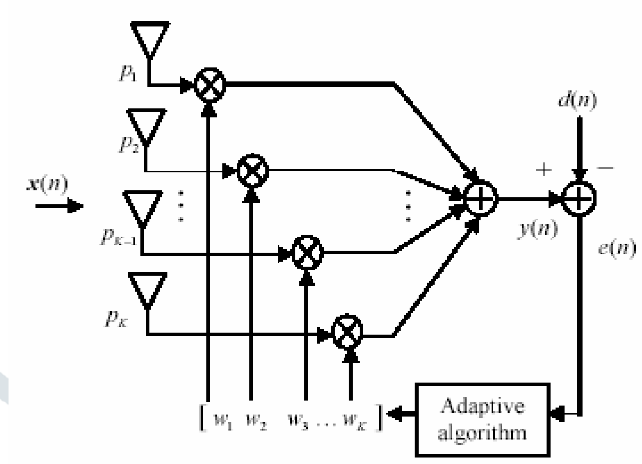

Fig. 4. Adaptive array Structure

The antenna array elements are shown as $P = \{p_1, p_2, \ldots, p_k\}$ and the respective weights are represented as $w = \{w_1, w_2, \ldots, w_k\}$. The adaptive algorithm tune the weights on the basis of $e(n) = y(n) - d(n)$ (7)

The adaptive algorithm applied in this paper is Conjugate Gradient method adaptive beamforming algorithm. For symmetric positive definite systems, the Conjugate Gradient method is an effective method. The approach works by creating iteration vector sequences, residuals for the iterates, and search directions for updating the iterates and residuals. The typical configuration of CGM for *n-1* antennas is shown in fig 5 where $w_1, w_2, \ldots, w_{n-1}$ corresponds to the respective weights and *y* is the output.

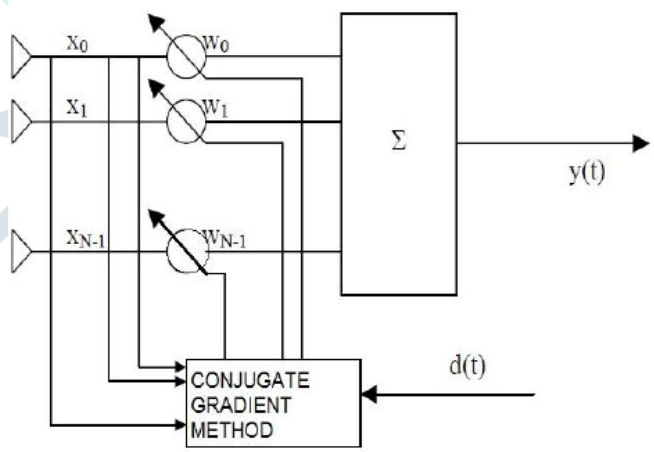

Fig. 5. CGM configuration

The adaptive estimation of the k^{th} iterate denoted by x^k is constructed in the CGM method as

$$x^k = x^0 + span\{r^0, A^1 r, \ldots, A^{k-1} r^{k-1}\}$$

such that $\left(x^k - \hat{x}\right)^T A\left(x^k - \hat{x}\right)$ is minimized. The exact solution of *Ax=b* is denoted as $\hat{x}$ and A is assumed to be symmetric positive definite matrix. In no more than *n* steps, the conjugate gradient iterates converge to the solution of $Ax=b$, where n is the size of the matrix. Two inner products are computed in each iteration of the procedure to compute update scalars that are defined to make the sequences satisfy specific orthogonal criteria. These criteria indicate that the distance to the real solution is reduced in some norm for a symmetric positive definite linear system.

Assuming that $x(t)$ as the signal received at the antenna and w^H as the output of the adaptive beamforming elements, the covariance matrix can be evaluated in terms of maximum likelihood estimation as

$$R(N) = {}^{1}\!/_{N}\sum X.X^{H} \qquad (8)$$

The optimal values of weight vector can therefore be written as

$$w = R^{-1}V \qquad (9)$$

Where V is the antenna array propagation vector and can be represented as

$$V = \begin{bmatrix} 1 & e^{j\xi d\sin\phi} & \dots & e^{j(k-1)\xi d\sin\phi} \end{bmatrix} \qquad (10)$$

The tuning laws are derived for the weight updates in terms of search direction vector p as

$$x^{k} = x^{k-1} + \alpha^{k} p^{k} \qquad (11)$$

Accordingly, the rule for updating the residuals $r^{k} = b - Ax^{k}$ as

$$r^{k} = r^{k-1} - \alpha A p^{k} \qquad (12)$$

The value of α is selected in such a way that $r^{k^T} A^{-1} r^{k}$ achieves its minima considering $\alpha = r^{(k-1)^T} r^{(k-1)} / p^{k^T} A p^{k}$

Similarly, the value of β^{k} is selected such that the values of r^{k} and r^{k-1} are orthogonal while updating the search direction algorithm through

$$p^{k} = r^{k} + \beta^{k-1} p^{k-1} \qquad (13)$$

The CGM algorithm mitigates the inter-symbol interference and provides a faster convergence and less mean square error. In the proposed research work, CGM adaptive algorithm is implemented for the beamforming of the patch antenna array feed network. The outcome of this feed network is then given to the parabolic reflector to achieve the desired radiation characteristics.

V. Results and Discussion

The radiation characteristics of the proposed design are evaluated through the simulation analysis through MATLAB software. The antenna parameters considered in this analysis are shown in table 1.

Table 1: Antenna parameters

Antenna Parameters	Value
Operating frequency(f_0)	6 GHz
Width of single patch(W)	51.25mm
Length of single patch(L)	40.01mm
Height	1.5mm
Number of elements	8
Distance between elements	0.5 λ
Feed line length	9.5mm
Radius of the field	0.5mm
Power radiated (Watts)	0.046
Effective angle(deg)	0.41 steradian
Directivity(dB)	14.832
Gain(dB)	14.8287
Intensity(Watts)	0.112
E(theta)	81.68
E(phi)	82.68

These variables are utilised to construct the electromagnetic scenario for evaluating the proposed smart antenna-based array feed for parabolic reflector performance.

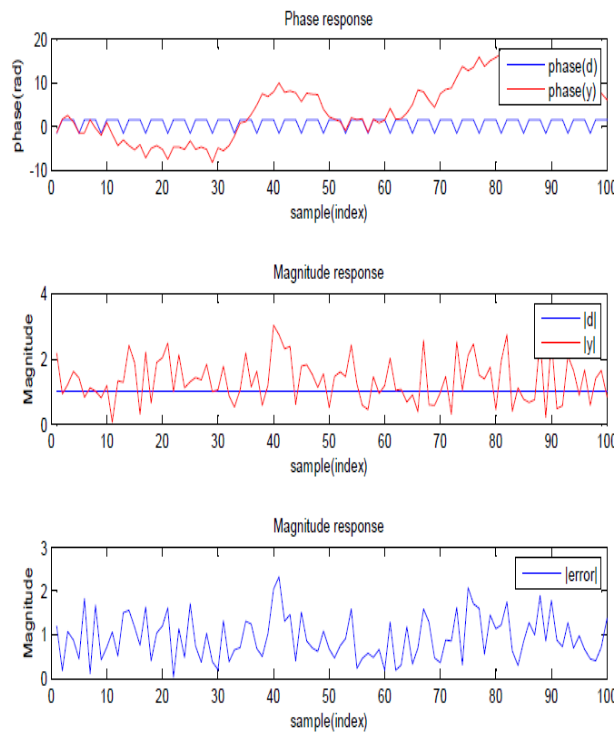

Fig. 6. Simulation result of 5 elements array using LMS algorithm for mu=0.001

Figures 6 and 7 depict a simulation of the CGM method based on phase, magnitude, and inaccuracy. Because it requires a pilot signal to detect the target signal and update the complex weights, CGM is a non-blind method. As a result, the findings of the CGM algorithm are compared to the reference signal in the diagram above. We looked at the results of the CGM algorithm when the learning parameter was set to 0.001 and 0.0001. Figures 8-10 demonstrate the relationship between mean square error and number of iterations. It has been discovered that when mu=0.1, the LMS and CGM algorithms do not converge after 50 iterations. However, we can observe that the CGM algorithm has a lower mean square error and better convergence than the LMS approach..

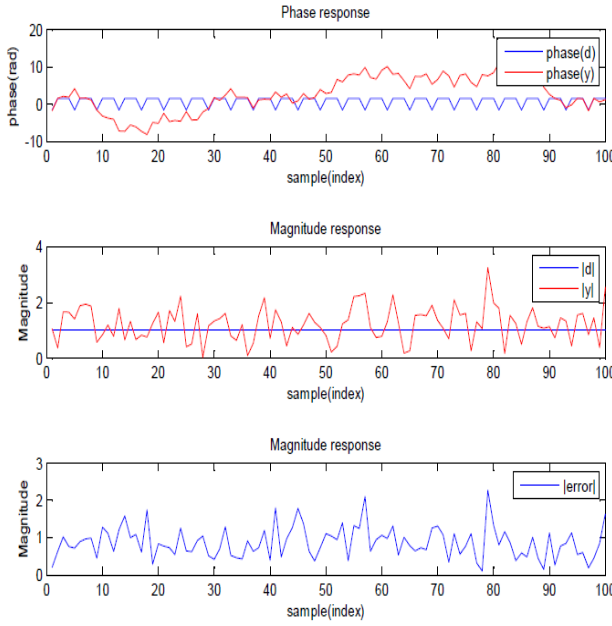

Fig. 7. Fig..Simulation result of 5 elements array using DFE-LMS algorithm for mu=0.001 and mu=0.0001

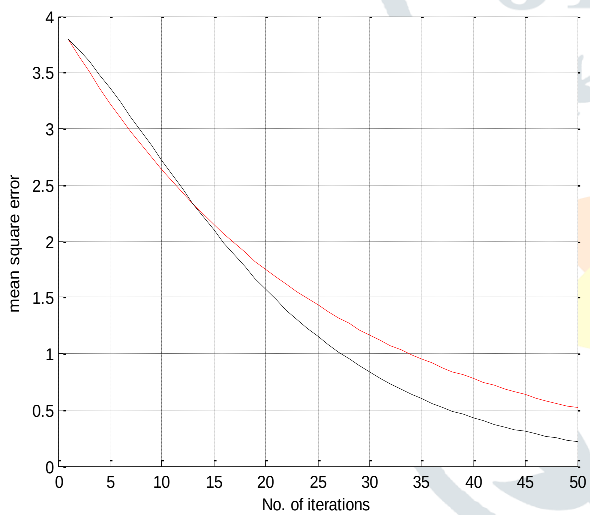

Fig. 8. Mean square error for mu=0.1.

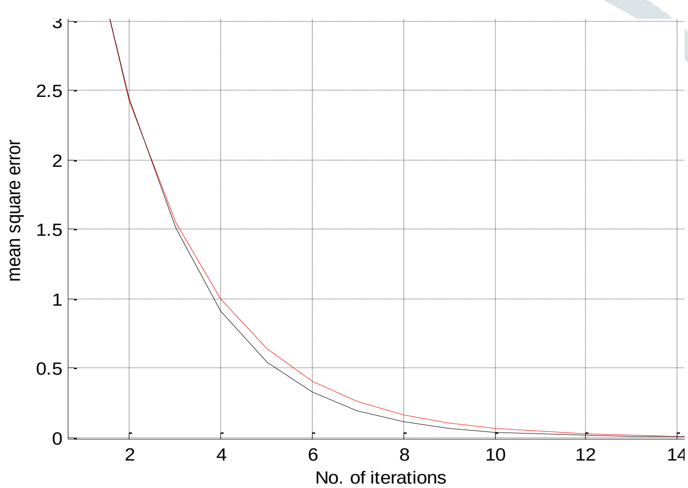

Fig. 9. Mean Square error for mu=0.2.

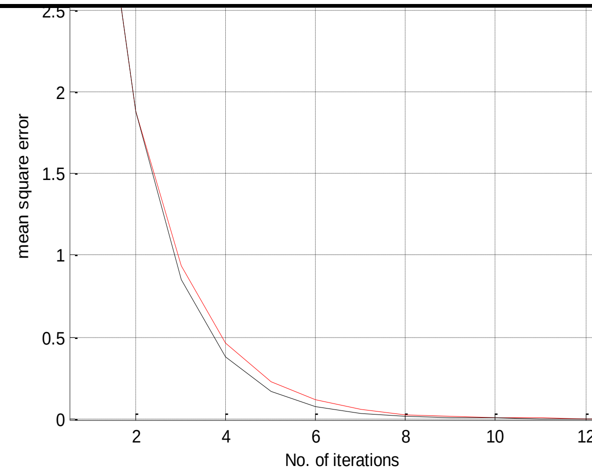

Fig. 10. Mean Square error for mu=0.3.

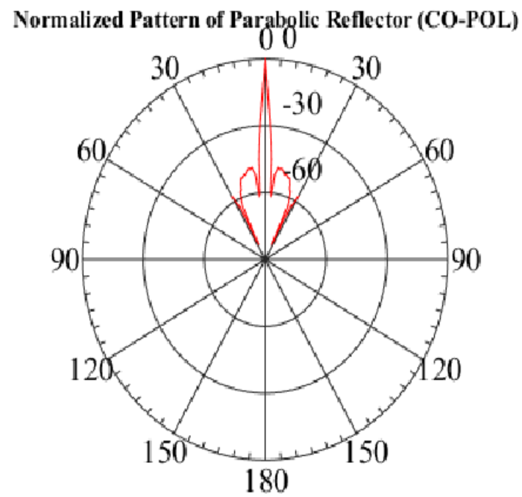

Fig. 11. Normalized pattern of Reflector

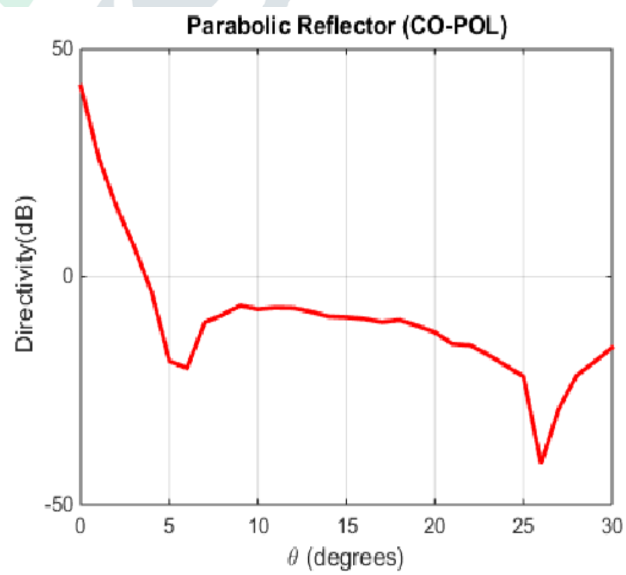

Fig. 12. Directivity of the parabolic Reflector

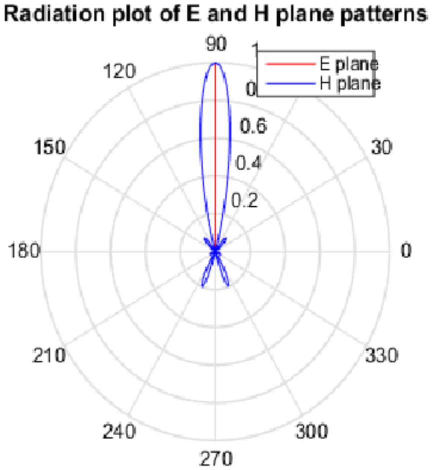

Fig. 13. Radiation pattern of Patch antenna array without beamforming

The radiation parameters of the parabolic reflector under examination are shown in Figures 11 and 12. Figure 13 shows the patch antenna array's radiation pattern without beamforming. Because the feed of the reflector antenna is provided a homogeneous power distribution, directivity is poor. The penetration capability of SOI for sky wave propagation must be increased, which can be accomplished by adding beam forming capability and adaptability to feed networks as needed according to signal orientation direction. The usage of beamforming techniques is used to apply beamforming to patch array feed. The implementation of the CGM method is shown in the graph of Fig.14.

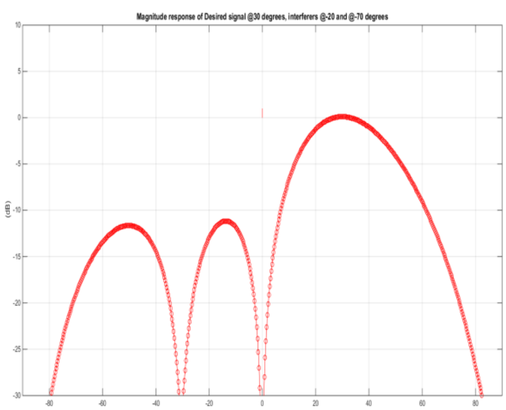

Fig. 14. Plot of CGM algorithm for patch array feed

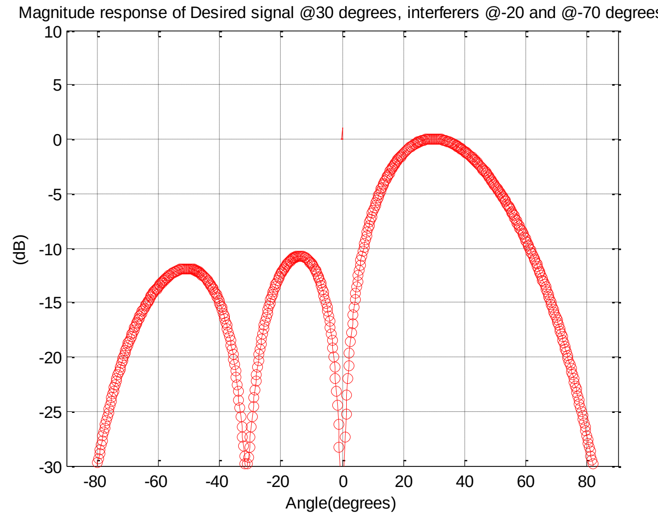

Fig. 15. Magnitude response for patch array feed

The radiation properties of the patch array feed designed in the proposed work are shown in Figures 15–16. The patch array feed's magnitude response and radiation plot are presented here. Figure 17 depicts the normalised pattern for a parabolic reflector, while figure 18 depicts the acute radiation pattern of the proposed smart array feed for a parabolic reflector employing a patch antenna using the CGM algorithm. The magnitude and phase response of the resulting design are shown in Figure 19.

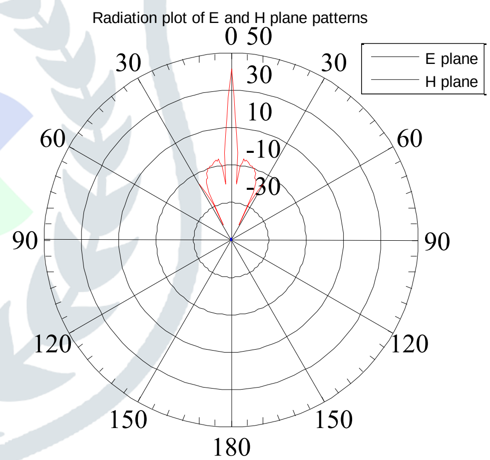

Fig. 16. Radiation Plot for patch array feed

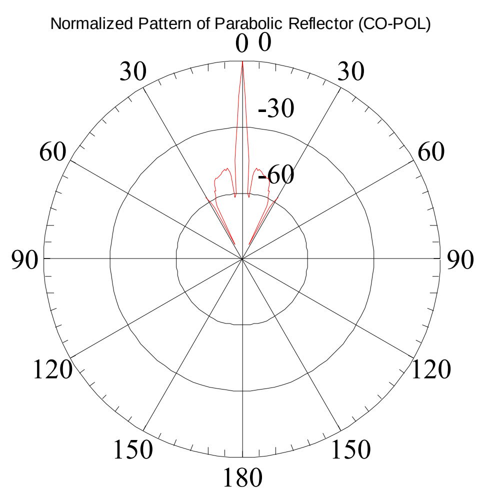

Fig. 17. Normalized pattern for Parabolic reflector

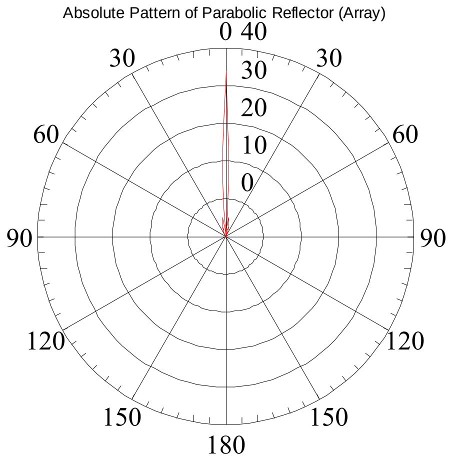

Fig. 18. Absolute pattern of parabolic reflector for patch array feed

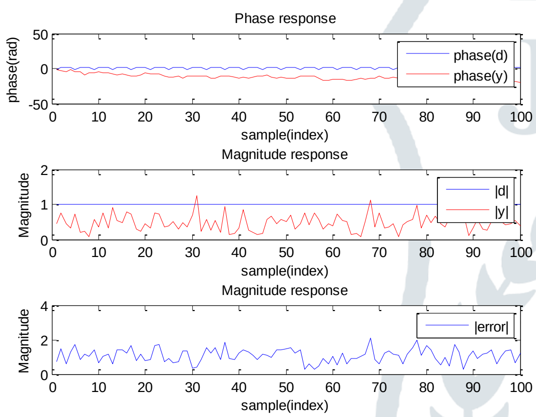

Fig. 19. Magnitude and phase response

VI. Conclusion

This paper proposes a patch array feed based on smart antennas. The parabolic reflector receives a regulated power distribution to improve its radiating characteristics. To investigate the various spectrum features of the antenna design, a rigorous analytical analysis was conducted. For the feed network, the suggested work uses an 8x1 rectangle patch array. The parabolic reflector is thought to be operating at a frequency of 6GHz with an F/D ratio of 0.36. The reflector's aperture illumination is set at 1400. The CGM algorithm is used to provide adaptive beamforming by modifying the array elements' excitation coefficients. The simulation analysis was carried out to ensure that the proposed design was effective. The improvement in directivity and antenna gain can then be seen in figures 16-18, which show the sharpness of the beam.

References

[1] T. Rappaport, "Wireless Communications, Principles and Practice", 2 ed., Prentice Hall, 2002.

[2] C. Balanis, "Antenna Theory: Analysis and Design", 2 ed., John Wiley & Sons, 2005.

[3] S. Lee and J. Lee, "Analysis Method of Parabolic Reflector Antenna, Communications Satellite", Development Group, ETRI, pp. 1324-1327.

[4] D. Pozar, "Microwave Engineering",2 ed., Wiley publications.

[5] D. K. Panda and S. Shaik, "Linear, Non -Linear Adaptive Beamforming Algorithm for Smart Antenna System", International conference of computer communication and control, IEEE, 2015.

[6] L.Thao, D.Loc,N.Tuyen,"Study comparative of Parabolic array antenna and phased array antenna",VNU Journal of Science, vol. 30, no. 3, pp. 31-36, 2014.

[7] G. Frank, "Smart Antenna for Wireless Communication", McGraw-Hill, September 2014.

[8] D. K. Panda, "DRLMS Adaptive Beamforming Algorithm for Smart Antenna System", International Journal of Applied Engineering Research, vol. 13, no. 8, pp. 5585-5588, 2018.

[9] D.K.Panda and S.Shaik, "BER Analysis of DFE-LMS Algorithm for Smart Antenna System", International Journal of Engineering and Technology, vol. 8, no. 2, pp. 1275-1278, Apr-May 2016.

[10] S. Kamboj and R. Dahiya, "Adaptive Antenna Array for Satellite Communication Systems", Proceedings of the International Conference of Engineers and Computer Scientists ,Vol 2, pp 19-21 March 2008, vol. 2, pp. 19-21, March 2008.

[11] N.Michishita, J.Shinohara, Y.Yamada, M.Islam, and N. Misran, "Design of an Array Feed Offset Parabolic Reflector Antenna by Using Electromagnetic Simulations and Measured Results", ACES journal, vol. 28, no. 12, December 2013., vol. 28, no. 12, pp. 1250-1258, 2013.

[12] A. Khalaf, A.Rahman , "A Hybrid NLMS/RLS Algorithm to Enhance the Beamforming Process of Smart Antenna Systems", International Journal on Antennas, vol. 10, 2014.

[13] D. K. Panda and S. Shaikh, "Performance Analysis of LMS, DFE-LMS Adaptive Beamforming Algorithm for Smart Antenna System", Far East Journal of Electronics and Communication, vol. 16, no. 1, pp. 119-129, January 2016

[14] J. A. Srar, K. Chung, And A. Mansour, "Adaptive Array Beamforming Using A Combined LMS-LMS Algorithm," IEEE Transactions on Antennas and Propagation, VOL. 58, PP. 3545–3557, NOV 2010.

[15] S. Bellofiore, J. Foutz, R. Govindarajula, I. Bahçeci, C.Balanis, "Smart Antenna System Analysis, Integration", IEEE transactions on antennas and propagation, vol. 50, no. 5, pp. 571-581, 2002.

[16] P. Saxena and A. Kothari, "Performance Analysis of adaptive Beamforming algorithm for Smart antenna system", International conference on future Engineering, IERI, no. 2014, pp. 131-137, 2014.

[17] A.Rao and N.Sharma, "Adaptive Beamforming Algorithms for Smart Antenna System", WSEAS Transactions on Communications, vol. 13, pp. 44-50, 2014.

[18] S. Baneerji and V. Dwivedi, "Adaptive antenna; Effect of signal to interference ratio on adaptive beamforming techniques", Journal of King Saud University Engineering Sciences, vol. 30, pp. 313-319, 2018.

[19] Cho, H., Lee, C.W., Kim, S.W., Derivation of a new normalized least mean squares algorithm with modified minimization criterion, Signal Processing, 2008, 89 (4): 692-695.

[20] C. Jethava and R. Karandikar, "Algorithms of Adaptive Beam Forming for Smart Antenna A Comparative Study", IOSR Journal of Electronics and Communication Engineering (IOSR-JECE) , vol. 8, no. 1, pp. 27-30, October 2013.

[21] Garg, R., Bhartia P., Bahl I. and Ittipiboon A. Microstrip Antenna Design Handbook Artech House Inc. Norwood MA, pp. 43-52,718-756, 2001.

[22] J. Shinohara, Y. Yamada, N. Michishita, M. Islam, and N. Misran, "Design of an array feed offset parabolic reflector antenna used for a simple earth station," Int. Conf. Space Science and Commun., Paper ID 81, 2011.

[23] J. Shinohara, N. Michishita, Y. Yamada, M. Islam, and N. Misran, "Measured electrical characteristics of an array feed offset parabolic reflector antenna," ISAP'12, POS2-19, pp. 1104-1107, 2012.