ISSN: 2584-0495 Vol. 2, Issue 11, pp. 1341-1348

International Journal of Microsystems and IoT

ISSN: (Online) Journal homepage: https://www.ijmit.org

A Novel Design of Pencil Beam Antenna for Beamforming at X-Band

Thirunavukkarasu G, Karteeswar K.P, Lathika M.V

Cite as: Thirunavukkarasu, G., Karteeswar, K. P., & Lathika, M. V. (2024). A Novel Design of Pencil Beam Antenna for Beamforming at X-Band. International Journal of Microsystems and IoT, 2(11), 1341–1348. https://doi.org/10.5281/zenodo.14960737

Published online: 29 November 2024

DOI: https://doi.org/10.5281/zenodo.14960737

International Journal of Microsystems and IoT
Vol.2, Issue 11, pp. 1341-1348; DOI: https://doi.org/10.5281/zenodo.14960737

A Novel Design of Pencil Beam Antenna for Beamforming at X-Band

Thirunavukkarasu G, Karteeswar K.P, Lathika M.V

[1]Department of Electronics and Communication Engineering, Kongu Engineering College, Erode, Tamil Nadu, India

ABSTRACT
The project introduces a prototype of a microstrip patch array antenna characterized by high gain, a narrow beam, cost-effectiveness, lightweight construction, and a low profile, allowing precise adjustments to its radiation patterns. The narrow beam design offers a significantly reduced coverage area compared to omnidirectional antennas, thereby mitigating interference risks associated with signal radiation into nearby sites. The project's primary objective is to engineer an X-band antenna for beamforming applications while incorporating an analog beamforming system. The overarching goal is to establish an effective and reliable system, enhancing security and safety measures. The 4 x 4 patch antenna array has been designed based on a rectangular patch antenna and simulated using HFSS. It is found to have a maximum gain of 11.1 dB at approximately 10 GHz, with notable parameters such as VSWR and return loss measuring at 1.01 and -51.36 dB, respectively.

KEYWORDS
X-band antenna; RADAR; drone detection; pencil beam antenna; Patch antenna array; Beamforming; X-band Radar; Return loss; VSWR

1. INTRODUCTION

Radar generates radio waves through a transmitter and has a receiver to examine the reflections. It is employed for finding and locating objects, including ships, aircraft, and other items. Radars are used to measure the characteristics of the water, monitor and identify items at sea level, and track insects and birds in the sky. Both electromagnetic power transmission and energy generation are accomplished by Radar at the precise target. The target position receives the returning signals once more. Today's Radar comes in a variety of forms, including weather, mapping, biostatic, Doppler, mono-pulse, passive, and weather-sensing. The four main parts of Radar are shown in Figure 1. A transmitter generates a signal. The transmit/receive switch is used to send and receive signals to the antenna. Antennas send these signals into the atmosphere, where they are subsequently returned. Once signals are received, they are recognized, boosted, and sent in video format.

Small drones flying at low altitudes can carry explosives and avoid detection, leading to concerns of unauthorized surveillance, targeted attacks, and information leaks. Existing detection systems are less efficient to track this, leaving airspace vulnerable. The goal is to create an effective and reliable narrow beam antenna for drone detection in order to enhance security and safety measures.

High-resolution radars are made especially for monitoring and detecting drones. For the purpose of characterizing drones, reflected signals are examined and contrasted with a database. As with radars for bird detection, the recorded signatures may also be utilized to filter out things that are not drone-like. With the help of this signal processing, detection performance is significantly increased, and false positives are reduced.

The project focuses on developing a novel design of narrow beam microstrip antenna for low altitude drone detection system that detects drones flying at lower altitudes. Detecting low altitude drones, or small unmanned aerial vehicles (UAVs), is crucial for maintaining security and public safety. These drones flying at lower altitudes, can be challenging to detect using traditional radar systems designed for larger aircraft.

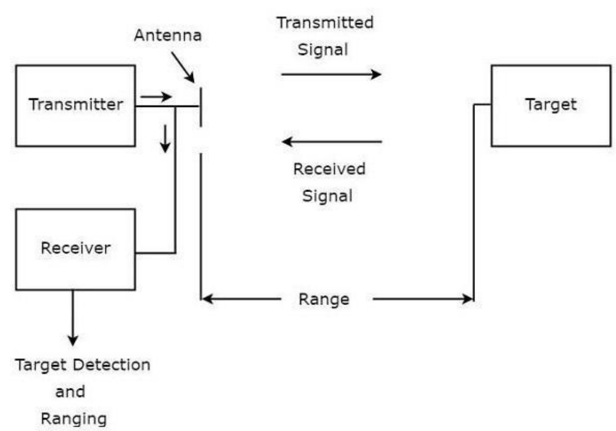

Fig. 1 Block diagram of RADAR

Reliable detection systems are essential to prevent unauthorized surveillance, protect airspace integrity, and mitigate risks such as collisions or unauthorized activities. and mitigate risks such as collisions or unauthorized activities. This introduction highlights the importance of effective detection technologies in addressing the evolving threats posed by these small, agile, and elusive UAVs.

The paper is organized as five sections starting from analyzing the literatures based on antenna design, notion of proposed antenna followed by its design procedure. The simulation results and conclusion come after this. The simulation results and the benefits are highlighted in the conclusion section.

2. RELATED WORKS

Radar antenna design requires narrow beam for locating the target. A research paper [1] explores X-band RADAR applications with focus on a 1x4 beam guiding array and a high gain 2x4 array. The latter exhibits exceptional performance in bandwidth, return loss, directivity, and gain. The study provides valuable information for RADAR antenna design. Growing use of drones is addressed in [2] predicting a substantial market expansion. Emphasizes challenges in computer vision for drone data and highlights the importance of further research in detection and tracking algorithms. Modern object identification methods are shown in [3] for drones, discussing two-stage and one-stage detectors. Evaluates drawbacks and hybrid approaches, providing a comprehensive overview of drone detection techniques.

A cost-effective solution of antenna design for Radar application is given in [4] with a 1x4 rectangular patch array for X-band applications. Outperforms single-element antennas, making it a compelling option for radar, satellite communication, and medical application. Use of microstrip patch array antennas for beamforming at sub-6 GHz is given in [5]. Highlights the superior performance of the 2x2 Quad element microstrip patch array, offering practical insights for wireless communication technologies. A survey on a Ku Band antenna array [6], optimizing for low side lobe levels and favorable cross-polarization. The promising results suggest potential practical implementation in the Ku Band frequency range.

A dual-band slot antenna is designed [7] for WLAN and WiMAX, emphasizing its high gain and directional multiband characteristics. The study provides valuable insights into antenna performance for wireless communication applications. A Comparison of dual, quad, and eight patch array antennas [8] using edge feeding techniques has been done. The study concludes that individual feed offers superior performance in terms of gain and directivity, contributing insights for antenna engineering. Another recent paper focuses on creating a passive radar system for UAV detection [9] using microstrip rectangular patches. The validated design meets requirements for radiation patterns, bandwidth, and gain, suggesting its potential in safeguarding critical locations. A linear array of rectangular microstrip patch antennas for X-band applications is discussed in [10]. The study satisfies X Band design standards, showcasing the antenna system's effectiveness for drone identification and detection in sensitive locations. A two-stage method is presented [11] employing GoF sensing and DRNN for drone signal recognition, spectrum localization, and classification. Achieves good results but may not work with unknown signals.

Another literature addresses [12] illicit drone activities, introducing a novel drone RF dataset. YOLO framework shows superior detection in multi-signal scenarios, with Deep Recurrent Neural Network DRNN comparable in classification. Acknowledges limitations and proposes exploration of unsupervised scenarios. Microstrip patch array antennas for satellite communication is illustrated [13], introducing a 2x2 microstrip array for satellite communication. Achieves significant bandwidth, gain, directivity, and efficiency. A rectangular array antenna-based hybrid beamforming model in massive MIMO for 5G is presented in [14]. Shows up to 99% reduction in computational complexity compared to fully digital beamforming, emphasizing cost-effectiveness. Another paper [15] introduces a dedicated miniature antenna for detecting airliners using demodulated ADS-B signals on drones. The antenna exhibits circular polarization, axial ratio maintenance, and successful detection up to 437 km. The challenges of amateur drone threats are addressed [16] using 5G millimeter-wave cellular infrastructures. Proposes a novel technology and system design for efficient detection, considering base station density, directional antennas, and available bandwidth. A literature review explores the rising challenges posed by amateur drones [17]. The paper advocates utilizing 5G millimeter-wave cellular networks for effective drone detection, highlighting factors such as base station density, directional antennas, and available bandwidth. The proposed system design aims to address the pressing need for efficient detection of small-sized drones.

A comprehensive antenna system is presented [18] for V2X applications, integrating multi-band elements and mmWave 5G beamforming phased array antennas. Demonstrates broad coverage and high isolation. A suspended conformal patch antenna (SCPA) is introduced [19] for constant-gain beam-switching phased arrays. Improves gain and beamwidth compared to suspended planar patch antenna (SPPA). Another recent paper focuses on dual and quad-element microstrip patch antenna arrays [20] for beamforming applications at 2.4 GHz. Aims to reduce interferences and enhance QoS for sensor arrays and 3G wireless networks. Phased array antenna shown in [21] is provided with four circularly polarized slotted waveguide elements, showcasing feasibility for analog beamforming at 9.6 GHz. Dual circularly-polarized beam-switching antenna array is introduced [22] for WiMAX applications, utilizing a Butler matrix for efficient beam-forming. Beam-steerable antenna array [23] is presented with a 4x4 Butler Matrix feed network for X-band applications, achieving a bandwidth of 2 GHz and effective coverage over 100° [23]. A modular beamformer for transmitting antenna arrays [24] in the DCS/PCS frequency band, demonstrates low return losses and impressive performance. Challenges in UAV-SAR systems is addressed in [25] and the author has proposed a 4x4 ax-shaped radiator array antenna for high-resolution, lightweight, and fully circular-polarized SAR. Simulation and experiments validate its effectiveness in achieving precise circularly polarized SAR capabilities.

3. PROPOSED ARRAY ANTENNA

The proposed method focuses on designing a cost-effective 4 x 4 microstrip patch array antenna for X-band frequencies, specifically optimized for drone detection. Key features include high gain, a narrow beam, cost-effectiveness, lightweight construction, and a low profile, allowing precise radiation pattern adjustments. Leveraging array antenna principles enhances control over beam direction, crucial for minimizing interference risks. The feeding mechanism incorporates an innovative inset strategy, manipulating spacing and length to control impedance effectively. A distinctive notch structure in the inset feed dynamically modifies the antenna's resonance frequency, optimizing overall performance. The design process begins with a single patch antenna, progressing to a scalable 4 x 4 array. Output properties are systematically contrasted with contemporary techniques, confirming the antenna's efficacy in drone detection scenarios.

Inspiration is drawn from a 1x4 microstrip phased array antenna designed for 5 GHz Wi-Fi on the Rogers RT/Duroid 6006TM, employing a switch line phase shifter. This serves as the basis for our high-gain microstrip patch array antenna for X-band RADAR applications. The antennas, adjusted for a 10 GHz central frequency, are built on cost-effective FR4 material, ensuring economic viability. Results from the studied antenna array [1] showcase a working band between 9.77 GHz and 10.15 GHz, a bandwidth of 380 MHz, and impressive metrics such as 15.82 dB directivity, -30.27 dB return loss, and a 15.5 dB peak gain for the recommended 2x4 element array. The switched line phase shifter and 1x4 element array enable a half-power beam width (HPBW) of 16.88° and beam steering of (θ, φ) = (16°, 0). This method strategically shifts from high-cost RT Duroid to cost-effective FR4 material, ensuring economic viability without compromising performance. The result is an advanced microstrip patch array antenna, offering heightened drone detection capabilities and contributing significantly to radar technology's advancement in complex mission scenarios.

4. DESIGN PROCEDURE

A 4 × 4 patch array antenna operating in the X-band frequency region is suggested for use in drone detection applications. Initially, a single patch antenna is created and its output characteristics are examined in order to do this. The ultimate 4 x 4 patch array antenna is then developed using the 1 x 4 patch array antenna as a model, and its output properties are examined and contrasted with the current technique. The substrate is essential to the antenna's design. Permittivity needs to be 2.20 ≤ r ≤ 12.0. Low loss tangent is used to reduce the dielectric power losses of the antenna. A 1.6 mm-tall FR4 substrate with a 2.2 Ɛ_r factor is used in this design.

The bandwidth and impedance properties of the antenna are significantly influenced by its patch width. It can be found in equation 1

$$w = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad (1)$$

Where,

$c = velocity\ of\ light\ in\ free\ space$

$f_c = resonating\ frequency$

$\varepsilon_r = dielectric\ constant\ of\ substrate$

Since E and H-field lines are partially present in both the substrate and the air, this is taken into consideration. The calculation makes use of equation 2.

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

This is a consequence of the fringing effects of the patch. Equation 3 provides the extension length.

$$\Delta L = 0.412h\left(\frac{\varepsilon_{reff}+0.3}{\varepsilon_{reff}-0.258}\right)\left(\frac{\frac{W}{h}+0.264}{\frac{W}{h}+0.8}\right) \qquad (3)$$

Length of the patch antenna is given by

$$L = \frac{c}{2f\varepsilon_{reff}} - 2\Delta L \qquad (4)$$

As an initial step, a single patch antenna (Figure 2) is designed with the following dimension given in Table 1. These values are calculated using the above formulas for the operating frequency of 10 GHz and the substrate value of 4.4.

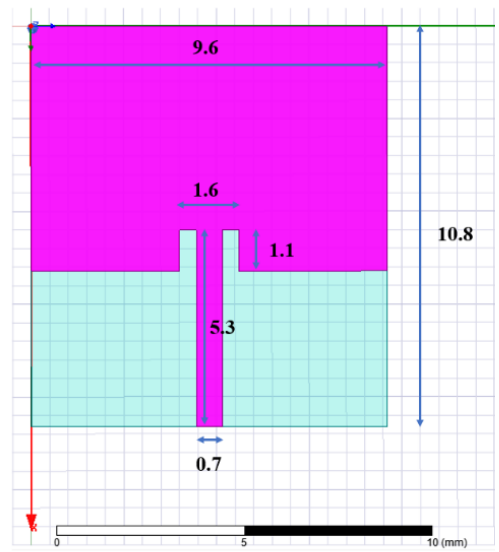

Fig. 2 Single Patch Antenna Design

This single patch antenna is the basic structure for the proposed array antenna.

Table. 1 Patch Antenna Dimensions

Parameter	Value in mm
Length of the patch (L)	10.8
Width of the patch (W)	9.6
Feed length (FL)	4.2

Feed width (FW)	0.7

As a second step, the linear array (Figure 3) of 4 elements is designed using the same dimension of the single patch antenna. The feed lines are connected using a strip line of thickness 0.4 mm and 48.7 mm length of the strip line upon connecting the patch antennas.

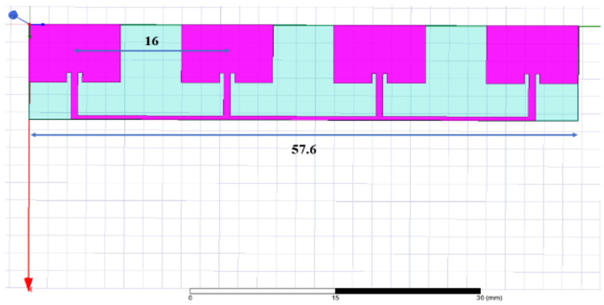

Fig. 3 Linear Patch Array Antenna 1x4

This linear array is stacked as array of linear array to obtain 4x4 patch array (Figure 4). The distance between the elements is kept as 16 mm which is a nearest value of half wavelength of X-band (10 GHz) to avoid interference

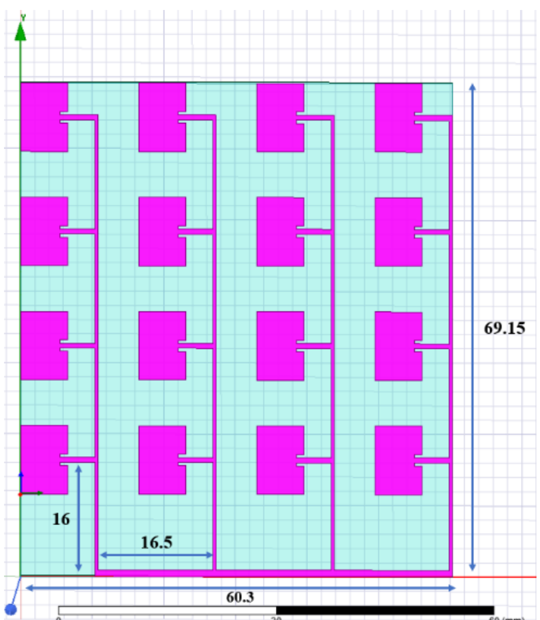

Fig. 4 Proposed Patch Array Antenna 4x4

Overall dimension of the proposed array antenna is 69.15 mm by 60.3 mm which looks compact in size and still provides pencil beam.

5. SIMULATION RESULTS

The proposed antenna array is designed with proper steps described in the previous section. It is simulated using HFSS simulator and the return loss, VSWR and radiation pattern are illustrated in this section.

The single element patch antenna has a return loss (Figure 5) of -42.76 dB at around 10 GHz frequency. It has a single frequency of resonance. The return loss plot indicates that the antenna's bandwidth is 591 MHz.

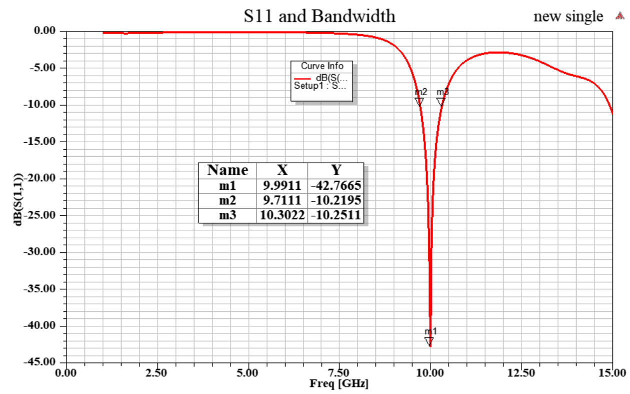

Fig. 5 Return Loss – Single Patch Antenna

The radiation pattern shows two dimensional and three dimensional gain plots (Figure 6a and 6b). It is the resultant radiation of a single rectangular patch antenna; hence the radiation is distributed as unidirectional with large beamwidth.

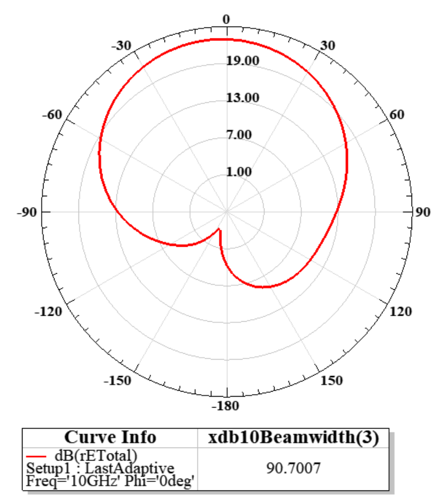

Fig. 6a 2D Gain Plot

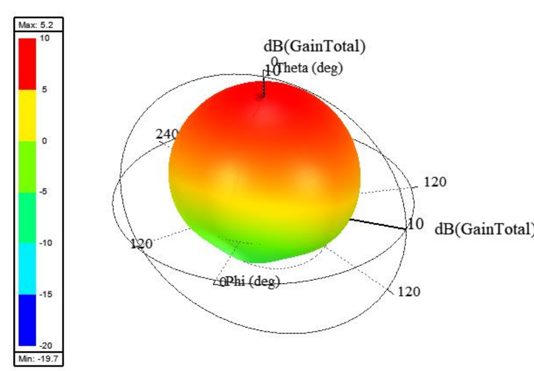

Fig. 6b 3D Gain Plot of Single Patch Antenna

It is observed from the three dimensional gain plot that maximum value of gain is 5.2 dB. This wide beam antenna is not suitable for beamforming applications. It makes the plan to go for array antenna which has a benefit of improved gain and narrow beam.

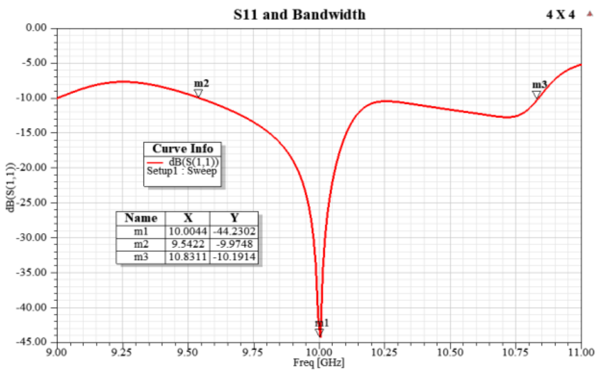

Fig. 7 Return Loss of Linear Array

The return loss (Figure 7) of linear array antenna is measured as -44.23 dB at around 10 GHz frequency comes in X-band. At the return loss of around -20 dB down the operating frequencies are limited to 9.8 GHz to 10.05 GHz.

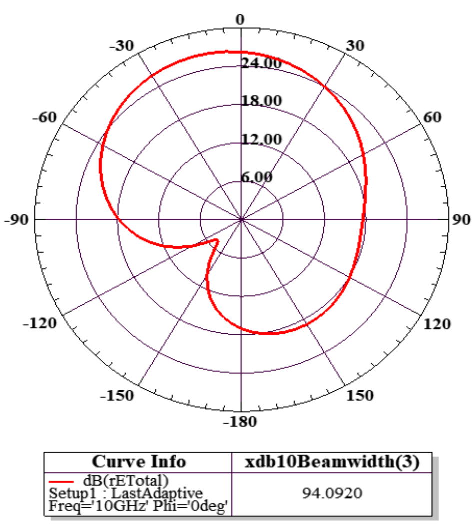

Fig. 8a 2D Gain Plot of Linear Patch Array

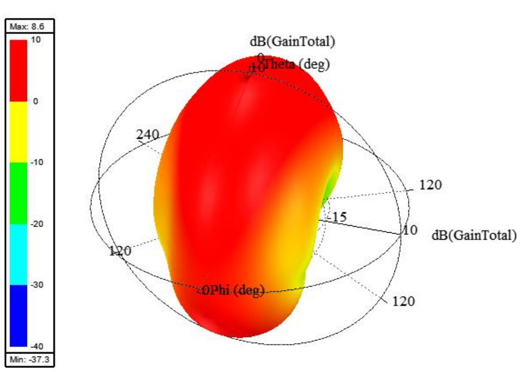

Fig. 8b 3D Gain Plot of Linear Patch Array Antenna

The two dimensional and three dimensional gain plots are given in figure 8a and figure 8b respectively. The radiation pattern shows like fan beam with wide beamwidth. The fan beam may also have preferred in some beamforming application, but it should have narrow beam in another side. The maximum value of gain is increased to 8.2 dB; however, the wide beam makes not suitable for proposed application.

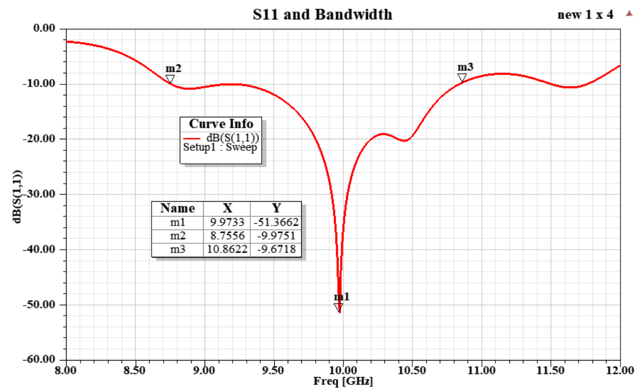

Fig. 9 Return loss of Proposed 4x4 Array antenna

The return loss of the 4 x 4 patch array antenna (Figure 9) has a value -51.36 dB around 10 GHz. The frequency band at -20dB down is from 9.8 GHz to 10.2 GHz. This shows that the proposed antenna array would work around 10 GHz of X band and suitable for radar applications.

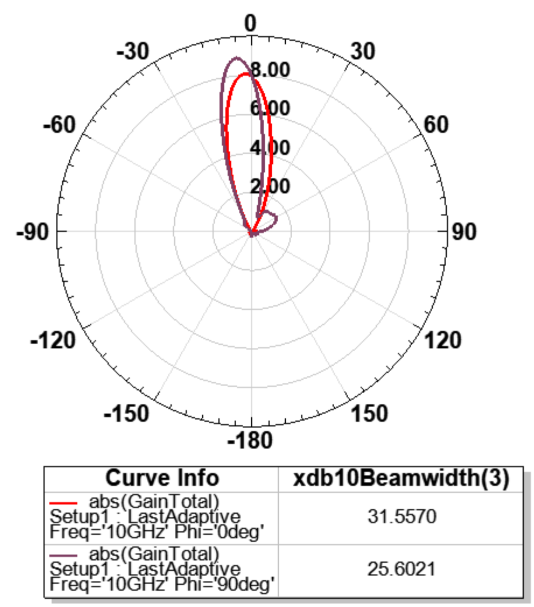

Fig. 10a 2D Radiation Pattern of Proposed 4x4 array

The proposed antenna is simulated and the 2 dimensional radiation pattern is ploted in Figure 10a as gain plot. It gives a huge main lobe and very small side lobe. Also the maximum gain is observed as 11.1 dB. Along with this gain improvement, it offers a narrow beamwidth. The half power beamwidth observed from the two dimensional gain plot is 15 degrees which is most suitable for beamforming applications.

The three dimensional radiation pattern is given in Figure 10b. from this figure it is observed that the beamwidth is quite narrow and is approximately a pencil beam pattern. This is a desired radiation characteristic for the beamforming in Radar applications.

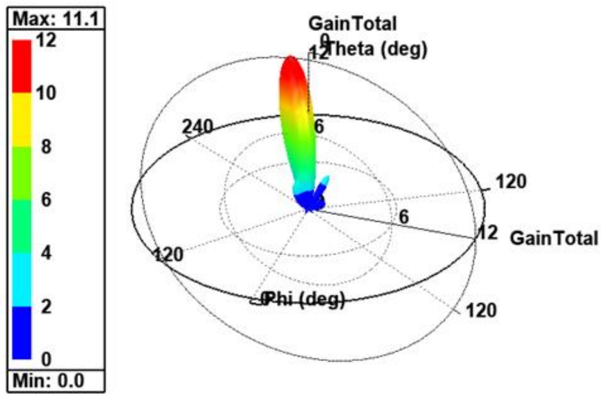

Fig. 10b Three dimensional Radiation Pattern of Proposed 4x4 array

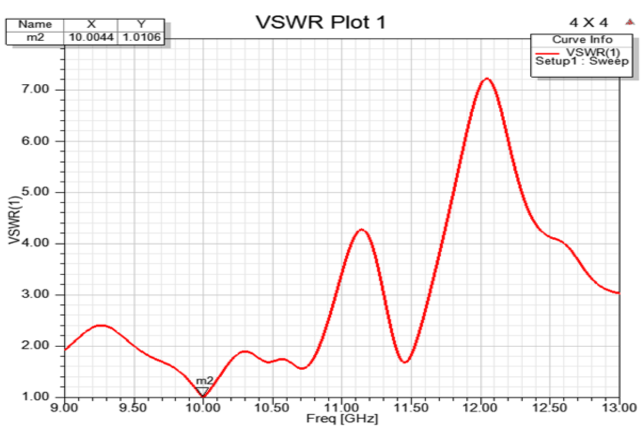

Fig. 11 VSWR of Proposed 4x4 array antenna

The voltage standing wave ratio (VSWR) of the antenna shows that it can be operated at 10 GHz, 10.9 GHz and 11.45 GHz all come under X-band. However, it has the least value of VSWR at 10 GHz, which is the proposed operating frequency in the antenna design.

.

6. CONCLUSION

The 4x4 array antenna for beamforming applications is simulated using HFSS. The return loss obtained is -51.36 dB which ensures the best impedance matching requirement. This is obtained by using very familiar inset feeding. Further, the VSWR is obtained 1.01 and it is much optimized value from simulation. Both the return loss and VSWR confirms the lower insertion loss. The HPBW is also 15 degrees and it is the pencil beam suitable for beamforming applications. The 4 x 4 patch antenna array, exhibiting a maximum gain of 11.1 dB at 10 GHz, attests to its effectiveness. As a result, based on the aforementioned claims, it can be inferred that this simulation results provide one of the best design. Moreover, the design complexity looks simple since it uses only rectangular patch antenna design. Boasting attributes such as high gain, pencil beam, cost-effectiveness, lightweight construction, and a low profile, it proves versatile across a range of scenarios.

REFERENCES

1. L.C.Paul, M.I. Hasan, R.Azim, M.R.Islam and M.T.Islam (2020). Design of High Gain Microstrip Array Antenna and Beam Steering for X band RADAR Application. Joint 9th International Conference of Informatics, Electronics and Vision (ICIEV) and 2020 4th International Conference on Imaging, Vision & Pattern Recognition (icIVPR) , Kitakyushu, Japan, 1-7. doi:10.1109/ICIEVicIVPR48672.2020. 9306519

2. P. Zhu et al. (2022). Detection and Tracking Meet Drones Challenge. in IEEE Transactions on Pattern Analysis and Machine Intelligence, 44(11) 7380-7399. doi: 10.1109/TPAMI.2021.3 119563

3. M. Nalamati, A. Kapoor, M. Saqib, N. Sharma and M. Blumenstein, (2019). Drone Detection in Long-Range Surveillance Videos. 16th IEEE International Conference on Advanced Video and Signal Based Surveillance (AVSS), Taipei, Taiwan, 1-6.

4. K.Leela Rani, (2017). 1x4 Rectangular Patch Array Operating at 10GHz Using Corporate Feeding Technique. International Journal of Engineering Development and Research 5(1), 845-848.

5. Thirunavukkarasu G., Murugesan G., Azrina Abd Aziz, Kowsikkumar S. (2023). Quad Element Beamforming Microstrip Antenna for Indoor User Equipment Localization at 6 GHz Band", Wireless Personal Communications, 130 (1) 2471–2494.

6. Vasujadevi Midasala, P. Siddaiah (2016). Microstrip Patch Antenna Array Design to Improve Better Gains. Procedia Computer Science, Volume 85(401-409), doi:10.1016/j.procs. 2016.05.181

7. M. van Rooyen, J. W. Odendaal and J. Joubert (2017). High-Gain Directional Antenna for WLAN and WiMAX Applications. in IEEE Antennas and Wireless Propagation Letters, 16(1) 286-289. doi: 10.1109/LAWP.2016.2573594

8. Naik, K. S., Srinivasu, K. Y. K. G. R (2018). Comparative analysis of dual, quad and octa element patch array antenna. International Journal of Innovative Science, Engineering and Technology. 5(2).

9. Mendes Ruiz, P., Begaud, X., Magne, F., Leder, E., & Khy (2023). Microstrip Antenna Array Design for Unmanned Aerial Vehicles Detection Radar. Advanced Electromagnetics. 12(3), 1-9 doi: https://doi.org/10.7716/aem.v12i3.2066

10. Mehmet Karahan, Mertcan Inal, Alperen Dilmen, Furkan Lacinkaya, Ahmet Nuri Akay, Cosku Kasnakoglu (2023). Microstrip Patch Antenna Design at 10 GHz for X Band Applications. doi: 10.48550/arXiv.2303.09963

11. J. Xu, W. Hong, Z. H. Jiang and H. Zhang (2019). Wideband, Low-Profile Patch Array Antenna With Corporate Stacked Microstrip and Substrate Integrated Waveguide Feeding Structure. in IEEE Transactions on Antennas and Propagation. 67 (2) 1368-1373. doi: 10.1109/TAP.2018.2883561

12. S. Basak, S. Rajendran, S. Pollin and B. Scheers (2022). Combined RF-Based Drone Detection and Classification. in IEEE Transactions on Cognitive Communications and Networking. 8(1),111-120. doi: 10.1109/TCCN.2021.3099114

13. T. T. S. Borel, A. R. Yadav and U. Shah (2019). Design of Rectangular Patch Array Antenna for Satellite Communication. 3rd International Conference on Computing Methodologies and Communication (ICCMC), Erode, India, 759-764. doi: 10.1109/ICCMC.2019.8819861

14. Priya, T.S., Manish, K. & Prakasam, P (2021). Hybrid Beamforming for Massive MIMO Using Rectangular Antenna Array Model in 5G Wireless Networks Wireless Pers Commun 120, 2061–2083 (2021) doi: 10.1007/s11277-021-08455-7

15. Sidibe, Alassane & Loubet, Gaël & Takacs, Alex & Ferré, Guillaume & Ghiotto, Anthony. (2020). Miniature drone antenna design for the detection of airliners. International Journal of Microwave and Wireless Technologies. 13(1) 1-7 10.1017/S1759078720000896

16. G. Fang, J. Yi, X. Wan, Y. Liu and H. Ke (2018). Experimental Research of Multistatic Passive Radar With a Single Antenna for Drone Detection. in IEEE Access 6 (1) 33542-33551 doi: 10.1109/ACCESS.2018.2844556

17. D. Solomitckii, M. Gapeyenko, V. Semkin, S. Andreev and Y. Koucheryavy (2018). Technologies for Efficient Amateur Drone Detection in 5G Millimeter-Wave Cellular Infrastructure. in IEEE Communications Magazine. 56(1) 43-50. doi: 10.1109/MCOM.2017.1700450

18. Lee, Changhyeong & Khattak, Muhammad & Kahng, Sungtek (2018). A Wideband 5G Beamforming Printed Array Clutched By LTE-A 4X4-MIMO Antennas with High Isolation. IET Microwaves, Antennas & Propagation. 12(1). doi: 10.1049/iet-map.2017.0946

19. Ko, Minbeom & Lee, Hojoo & Choi, Jaehoon (2020). A planar LTE/sub-6 GHz MIMO antenna integrated with mmWave 5G beamforming phased array antennas", IET Microwaves, Antennas & Propagation.14(1). doi: 10.1049/iet-map.2019.0849

20. S. Meerabeab, V. Jantarachote and P. Wounchoum 2022). Design and Parametric Study of a Suspended Conformal Patch Antenna. 2022 19th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON), Prachuap Khiri Khan, Thailand. 1-4. doi: 10.1109/ECTI-CON54298.2022.9795443

21. Abbas, Syed Muzahir & Ali, Rana & Nawaz, Hamza & Saleem, Ilyas & Khan, Shahid (2012). Microstrip Antenna Array for Beamforming Systems. Przeglad Elektrotechniczny 2012(1)170-173.

22. Elhefnawy, Mohamed (2020). Design and simulation of an analog beamforming phased array antenna. International Journal of Electrical and Computer Engineering (IJECE), 10 (1) 1398. doi: 10.11591/ijece.v10i2.pp1398-1405

23. Mousavi Razi, Zahra & Rafiei, Vahid & Denidni, Tayeb (2021). Beam-Switching Antenna Array with Dual-Circular-Polarized Operation for WiMAX Applications. AEU - International Journal of Electronics and Communications, 137 (1) 153796 doi: 10.1016/j.aeue.2021.153796

24. Mekala Harinath Reddy, David Siddle, D. Sheela (2022). Design and implementation of a beam-steering antenna array using butler matrix feed network for X-band applications. AEU - International Journal of Electronics and Communications, 147(1) 154147. doi: 10.1016/j.aeue.2022.154147

25. H. Kashihara, J. T. S. Sumantyo, Y. Izumi, K. Ito, S. Gao and K. Namba (2023). X-Band Microstrip Array Antenna for UAV Onboard Full Circularly Polarized Synthetic Aperture Radar. in IEEE Transactions on Antennas and Propagation. 71(2) 1943-1948. doi: 10.1109/TAP.2022.3232745

AUTHORS

Thirunavukkarasu G is an Assistant Professor in the Department of Electronics and Communication Engineering, Kongu Engineering College. He received his B.E. degree in Electronics and Communication Engineering from SSM college of Engineering, Namakkal Dt., Tamil Nadu. He received his M.E., in Communication Systems from College of Engineering, Anna University Chennai, India in 2009. He is currently pursuing PhD., in Information and Communication Engineering at Anna University Chennai, India. He is an active member of IEEE and Communication

Society under IEEE Madras Section. His areas of interest are wireless communication, MIMO and array antennas, Radar, RF system design and deep learning.

Email: thirueceinnovate@gmail.com

Karteeswar K.P received his B.E. degree in Electronics and Communication Engineering from Kongu Engineering College, Erode, Tamil Nadu, India in 2024. He is an active member of IEEE and Communication Society under IEEE Madras Section. His areas of interest are embedded systems, wireless communication and Radar systems.

Email: karteeswarkpk@gmail.com

Lathika M.V. received her B.E. degree in Electronics and Communication Engineering from Kongu Engineering College, Erode, Tamil Nadu, India in 2024. She is an active member of IEEE and Communication Society under IEEE Madras Section. Her areas of interest are embedded systems, PCB design and wireless communication.

Email: lathikamuruganandham@gmail.com