Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 44 No. 5 2023

Design and Implementation of Reconfigurable Frequency and Polarization Microstrip Patch Antenna for X-Band Application

[1] Devesh Kumar, [2] Anwar Shahzad Siddiqui, [3] H. P. Singh, [4] M. R. Tripathy, [5] Ward Ul Hijaz Paul

[1] [2] [5] Department of Electrical Engineering, Jamia Millia Islamia, New Delhi
[3] [4] Department of Electrical and Electronics Engineering, Amity University, Noida

Corresponding author: Ward Ul Hijaz Paul (mail: wardulhijazpaul@gmail.com)

Abstract: - A rectangular frequency and polarization reconfigurable microstrip patch antenna with dimensions 9.12x6.49mm has been designed which is suitable for X band applications. The final design has been presented in three gradual steps by cutting slots on the four corners of the patch and the ground. A dielectric material "FR4 epoxy" with dielectric constant of 4.4 is used as a substrate for the proposed antenna. The designed antenna parameters are calculated at 10ghz frequency with offset microstrip line feed mechanism. In this paper, the current on radiating patch is redistributed by using PIN diodes. By changing the state of the diodes, both frequency and polarization reconfiguration is achieved.

Keywords: PIN Diodes, FR4 Epoxy, Microstrip Patch Antenna, Return Loss, Gain Plot, LHCP, RHCP, Reconfigurable Frequency, Reconfigurable Polarization.

I. INTRODUCTION

A few decades back, wired technology prevailed, and it was hard to imagine communication between two devices (Usually electrical or electromechanical equipment) without any physical contact between them. With the emergence of electronic devices and the advancements of wireless technologies, communication devices became more efficient, sophisticated, and compact. Also, user got more freedom as the communication devices (User Equipment) became portable i.e., Mobile. This revolution was brought about with the everlasting contribution of Antennas. Antennas made sharing of information between two electronic devises possible without any physical contacts being required for transmission of electromagnetic signals, rather the atmosphere became the medium.

Multidimensional and wide range of applications and features attracted a huge audience and as a result number of wireless devices have increased exponentially. Multi-Function antennas have been in demand ever since the wireless technologies started to boom. Compact size and economic nature of microstrip antennas made them easily integrated, portable and easily available for communication devices. However, these are categorized under narrow band antennas and their working range is usually limited to a single band. Thus, in order to build a multi-band system, a collection or an array of such single-band antennas with proper configuration is required. Integration of parasitic elements and/or addition of slots in patches or ground plane can be an approach to solve the problem but with a cost of compromised polarization purity, reduced bandwidth, and increased dimensions.

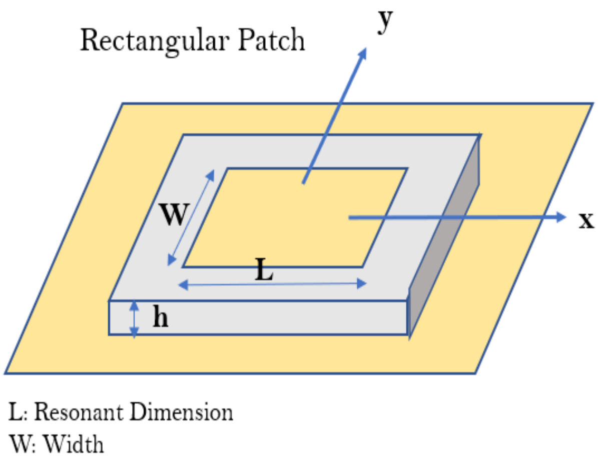


Fig 1. A typical microstrip antenna

A relatively new class of antennas, called reconfigurable antennas have gained much popularity in no time, the ability to adjust their operating frequency, radiation pattern and polarization dynamically by altering the radiated field of effective aperture has been the reason of this popularity [1]. These antennas salvage their dimensions at different operating bands. These are designed such that different parts of the body resonates at different desired calculated frequencies.

In the past few decades, this category of antennas is gaining popularity due to their ability to reconfigure certain characteristics dynamically as mentioned above. In this paper microstrip patch antenna is used as a platform to design reconfigurable antenna. A typical microstrip patch antenna has been shown in Fig. 1. The necessity of improved bandwidth gain performance can be accomplished with the accommodation of reconfigurable antenna. Solid state switches like pin diode [2], varactor diode and Radio Frequency Microelectromechanical System [3] are used to produce reconfigurable performance parameters of the antenna.

II. LITERATURE REVIEW

The versatile nature and wide range of applications of reconfigurable microstrip antennas has resulted in an exponential increase in their demand. With the advancement of electronic device fabrication processes, many scientists, researchers, and scholars have shown interest in exploring the possibilities and enhancing the capabilities of microstrip antennas in order to meet the demands of next generation communication devices. In this section some recent contributions are discussed in brief which have also being a motivation for the proposed design.

A recent literature proposed a reconfigurable circular microstrip patch antenna which finds application in the S, C and X bands. The proposed design has the ability to operate on 23 different frequencies starting from 3.24 GHz to 9.3 GHz. The proposed antenna can also exhibit polarization reconfiguration between one of four polarizations: RHCP, LHCP, Linear Polarization and Elliptical Polarization at different frequencies and different modes. In addition to the mentioned capabilities, it also shows pattern diversity. The simulation results were compared with those of reference antennas and were found fit for various applications for example, LTE, WIFI etc. and in upcoming 5G enabled communication devices [4].

Another similar literature proposed a reconfigurable patch antenna having LHCP, RHCP and Linear Polarization states. The ground plane consists of loop slots having two perturbation elements used for exiting circular polarization waves. Each slot consists of a PIN diode in order to change the direction of current flow which in turn decides the polarization state at any instant. Antenna performance is not affected by the slots and PIN diodes, the reason being that they are not on the patch. The effectiveness of the anticipated design was verified with the results simulated and the measured values calculated. The proposed reconfigurable patch antenna has good performance, compact dimension and dynamic reconfigurable polarization which can find application in 2.4 GHz wireless communication systems [5].

A recent publication proposed a single-fed antenna with ring-slot having the ability to reconfigure the polarization at predefined frequencies [6]–[8]. The switching of polarization is being done by toggling the two inherent states of a PIN diode namely ON state and the OFF state on the ring-slot. The proposed design consisted of a probe-fed slotted circular patch, ground plane and PIN diode switches. The feasibility of the proposed deign was demonstrated using a prototype operating at 2.4GHz band [9]. Another publication proposed a novel reconfigurable microstrip antenna having the ability to change its polarization. The design has a simple structure consisting of a corner-truncated square patch, a microstrip line feed and slight triangular conductors four in number. Patch has individual and independent biased PIN diodes which enables the structure to yield linear or left-sense/right-sense polarization in accordance with the bias voltages. Results show low cross-polarization levels while operating for the linear state and decent axial ratios for the circular state [10]. Another publication explores the possibility of expanding the bandwidth by using the concept of planar monopole patch [11].

A lot of research and development has been taking place on frequency reconfigurable antennas as well, one such work was presented in a recent publication. The publication proposed a design of an X-band frequency reconfigurable patch antenna. The working of the proposed design was demonstrated using PIN diodes. In order to comprehend the PIN diode effect, square slot was introduced. While realization of frequency tuning was done by changing the effective electrical length, which in turn was controlled by switching between distinct inherent states of PIN diodes by the application of proper bias voltages along the slot of antenna. In forward bias of the PIN diode, the current passed through outer ring giving a ±60 MHz tuning of frequency corresponding to an applied bias of 3 Volts [12].

Another recent literature proposed a pentagon shaped microstrip antenna having an operating frequency of 7.5GHz, a demonstrated -43.48dB return loss, 3.49dBi gain and 6.8627dBi directivity, for a single band operation. In order to further increase the gain and directivity of the proposed antenna a 1x2 and 1x4 array has been designed. Using varactor diodes, the conventional patch antennas have been frequently reconfigured to operate in dual bands. Such kinds of antennas can be used for defence and related applications. This can also find application in communication in X band (8 GHz to 12 GHz) for example the satellite communication and for RADAR applications [13].

A hexagonal reconfigurable patch fed by CPW, simulated on RT Duroid5880 was proposed in one of the reviewed literatures which finds application in WLAN, C and WiMAX bands. The radiation efficiency of the proposed antenna was found to be in the range of 78 to 94% with a gain of 3.4 to 6.32dBi. The dimensions of the proposed antenna are very compact with a radiation pattern in E-plane resembling that of a decent dipole with less co polarization. Excluding the interfering bands for WLAN, C and WiMAX the fractional bandwidth of the proposed design was about 153.62%. in addition, on the complete operating band, a group delay of less than or equal to unity has been maintained, it must be noted that antennas with such attributes like high bit rate and short-range communication exclusively find application and are demanded in military and radar systems [14]–[18].

Describing a novel frequency reconfigurable circularly polarized microstrip patch antenna, another publication has put forward an antenna design which consists of varactor diodes (four in numbers), lumped capacitors (two in numbers) and a square radiating patch. The square patch can be exited in dual-orthogonal resonant modes simultaneously with a coaxial probe [19]–[23]. Generating and tuning a circular polarization operating frequency is done by decreasing the resonant frequencies of the two modes which in turn is done by increasing the equivalent capacitance values of the four varactor diodes meanwhile the two lumped capacitors come in action to produce a difference between the two resonant frequencies [24], [25]. In the proposed design, single DC voltage is needed to change circular polarization operating frequency. The circular polarization frequency was found to be reconfigurable between 1.97 GHz and 2.53 GHz as a result of experimentation, also the results show appreciable circular polarization performances at each reconfigurable frequency [26], [27].

Stair slots on the ground were experimented with and proposed by a recent publication for a polarization reconfigurable rectangular patch antenna. Along with the slots two PIN diodes are used in order to switch the polarization of antenna between Linear Polarization, LHCP and RHCP [28].

III. DESIGN AND SIMULATION

In this literature we propose three different designs of a frequency and polarization reconfigurable microstrip patch antenna for X-band application. The proposed design has been simulated on 'ANSYS HFSS' software. The radiation takes place due to fringing fields along the edges of length of patch. The proposed antenna utilizes the offset microstrip line feeding mechanism in which the radio frequency power is directly fed to the patch. This literature focuses on comparing, plotting, and analysing the results of three designs of the microstrip patch antenna.

A. *Antenna Design*: We propose three different antenna designs which are simulated using HFSS, a popular antenna simulation software for research and development. The three proposed antenna designs can be derived from a base design. The designs have been explained below in detail.

1) *Antenna Design 1:* The first antenna design acts as a base design for rest of the three antenna designs. an offset microstrip line feed mechanism has been used as contacting method. The feed parameters corresponding to the design are as follows; feed width = 0.68mm, feed length = ($\lambda g/4$) mm, where λg is guided wavelength. The simulated antenna comprises of a metal patch of dimension 6.48mm×9.12mm, usually made of copper and is united with a feed line and a 50Ω impedance transmission line. This arrangement is then stacked on a substrate having a thickness of 1.5mm. This is usually done in the laboratory using a highly controlled chemical process called 'photo etching'. At the other side of the substrate there is a thin plane with negligible thickness acting as the ground plane. A prototype of the antenna design is shown in Fig. 2.

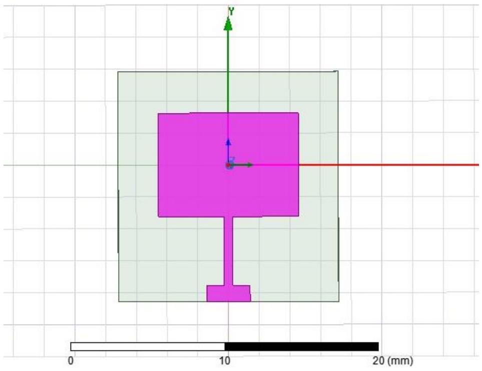


Fig 2. Simulation prototype top view of first antenna design

2) *Antenna Design 2:* In order to derive the second proposed antenna design, the four corners of the patch are cut into four separate square segments. The four corners' segments hence formed are separated from the patch by a narrow slot. Four diodes namely, D1,D2,D3 and D4 are integrated between the patch and the corner segments. The placement of the diodes has been done in a way that their directions are alternate. The simulation prototype of antenna design two is shown in Fig. 3. The PIN diodes assume resistive properties in forward and capacitive properties in reverse biased conditions as shown in Fig4. The value of forward resistance in the proposed model is taken as 1 ohm and the reverse capacitance is taken as 0.03 pf.

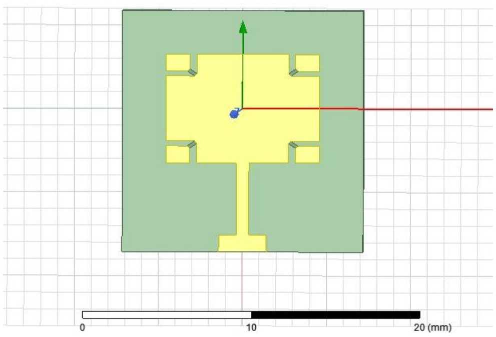


Fig 3. Simulation prototype top view of second antenna design

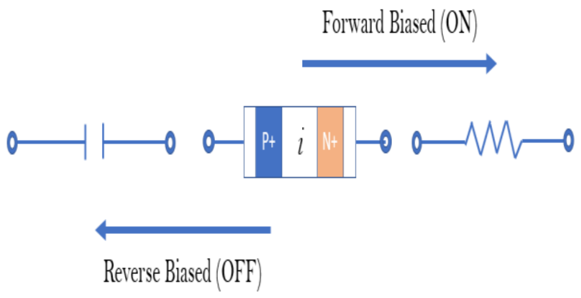


Fig 4. Forward and reverse bias behavior of a PIN Diode

3) *Antenna Design 3:* The final design i.e., the third design, has been derived by modification of the second design. In order to derive this design, we introduce slots in the ground plane. The position of slots in the ground plane is chosen in such a way that the edges of slots in the patch overlap with the edges of slots in the ground plane. Simulation prototype of antenna design three is shown in Fig. 5. After successful simulation of the proposed designs, the final antenna design was fabricated. The top, bottom and side view of the fabricated antenna has been shown in Fig. 6, Fig.7 and Fig8 respectively.

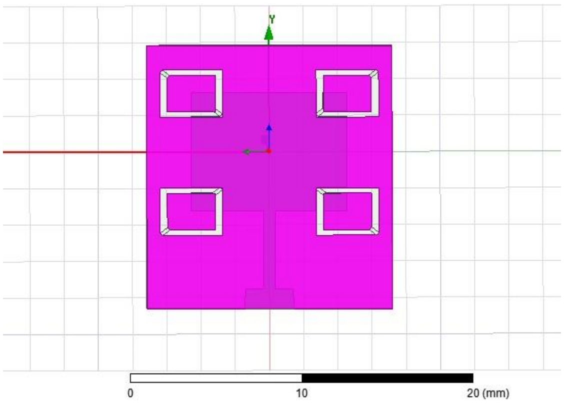
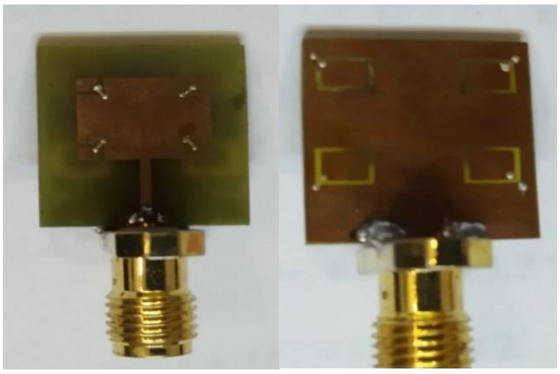


Fig 5. Simulation prototype top view of third antenna design



(a) (b)

Fig 6. (a) Top view of fabricated antenna (b) bottom view of fabricated antenna

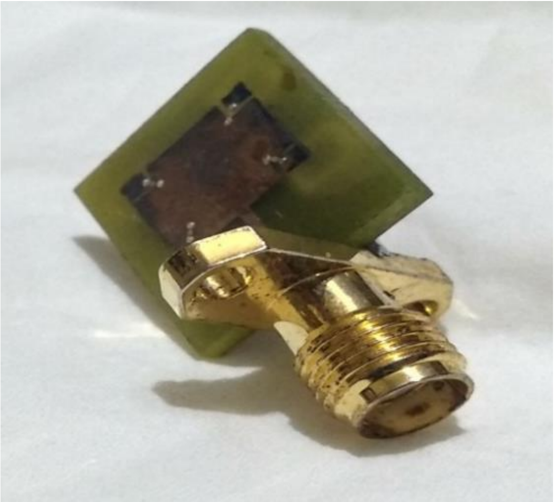


Fig 7. Side view of final fabricated antenna

B. *Design Parameters:* The design parameters and equations referred during the design process of the proposed antennas are given below.

Wavelength of resonant frequency:

$$\lambda = \frac{c}{f} \tag{1}$$

Where c is the speed of light and f is the Resonant Frequency.

1) *Calculation for Patch:*

$$w = \frac{c}{2f}\sqrt{\frac{2}{\epsilon_r + 1}} \tag{2}$$

$$L = L_{eff} - 2\Delta L \tag{3}$$

Where,

$\epsilon_r = Dielectric\ Constant\ of\ the\ Substrate$

$w = width\ of\ the\ patch$

$L = Length\ of\ the\ patch$

$\Delta L = Normalixed\ Extension\ in\ length$

$L_{eff} = Effective\ Length$

$$L_{eff} = \frac{c}{[(2f)(\epsilon_{reff})]} \tag{4}$$

Where, $\epsilon_{reff} = Effective\ Dielectric\ Constant$

when $\frac{w}{h} < 1$, we use

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[\left(1 + 12\frac{h}{w}\right)^{-\frac{1}{2}} + 0.04\left(1 - \frac{w}{h}\right)^2\right] \tag{5}$$

The normalized extension in length is given by:

$$\Delta L = 0.412h\frac{(\epsilon_{reff} + 0.3)(\frac{w}{h} + 0.264)}{(\epsilon_{reff} - 0.258)(\frac{w}{h} + 0.8)} \tag{6}$$

2) *Calculation for Feed:*

L_f (Length of feed) = $\lambda_g/4$

$$\lambda_g = \frac{300}{f_{Ghz}\sqrt{\epsilon_{reff}}} \tag{7}$$

3) *Transmission Line:*

$$w_t = \frac{7.48 \times h}{e^{\left(z_o \frac{\sqrt{\epsilon_r + 1.41}}{87}\right)}} - 1.25 \times t \tag{8}$$

Where,
w_t= width of transmission line
t = trace thickness

4) *Substrate:* The ground plane dimensions can be given as in the Equation(9), (10) and (11):

$$L_g = L + 6h' \tag{9}$$

$$W_g = w + 6h' \tag{10}$$

$$h' = \frac{0.0606\lambda}{\sqrt{\epsilon_r}} \tag{11}$$

5) *Radiation Box:* Radiation Box dimensions are as given by the Equation (12), (13) and (14):

$$L_{rb} = \frac{\lambda_g}{6} + \frac{\lambda_g}{6} + L_g \tag{12}$$

$$W_{rb} = \frac{\lambda_g}{6} + \frac{\lambda_g}{6} + W_g \tag{13}$$

$$H_{rb} = \frac{\lambda_g}{6} + \frac{\lambda_g}{6} + h \tag{14}$$

IV. RESULTS AND DISCUSSION

The three proposed designs have been simulated using ANSYS HFSS software. This section describes the simulation results of the three proposed designs.

A) *Antenna Design 1:* Fig 8(a) shows the S Parameter Plot of the first design. The frequency at -10dB ranges from 9.11GHz to 9.67GHz giving a bandwidth of 0.56GHz while the values of resonating frequency and return loss are 9.38GHz and -25.5038dB respectively. Fig 8(b) shows that for all values of ***phi*** the maximum gain is 4.0961dBat ***theta*** equals to 8 degrees.

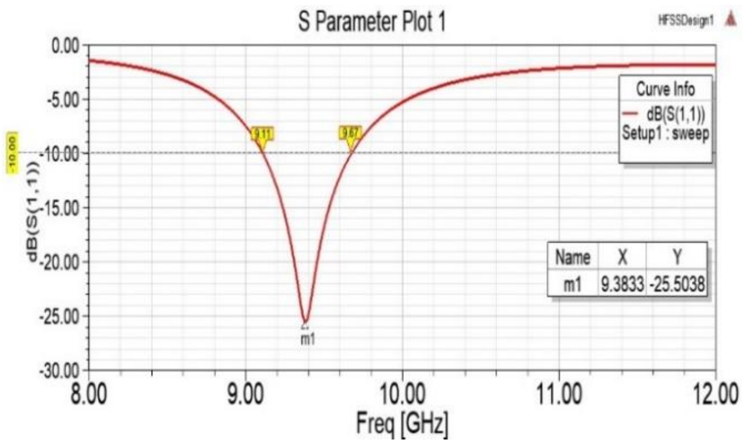


Fig 8 (a). Side view of final fabricated antenna

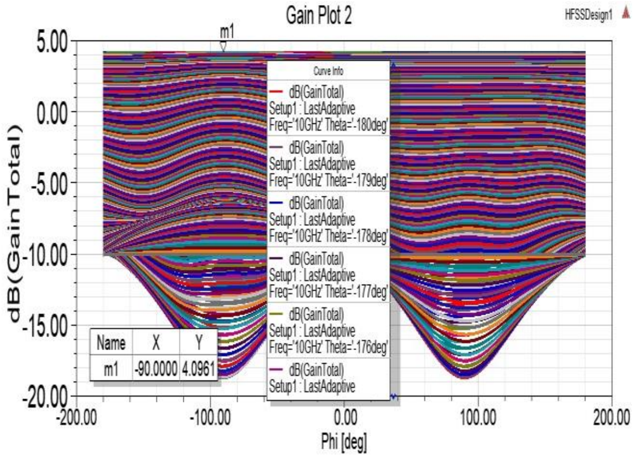


Fig 8 (b). Side view of final fabricated antenna

B) *Antenna Design 2:* The simulation results for antenna design two are shown in Fig. 9(a), 9(b) and 9(c). Bandwidth of the proposed antenna design can be calculated for the frequency range 9.22GHz to 9.78GHz, as seen in Fig. 9(a). Bandwidth is found to be 0.56GHz while the values of the resonating frequency and return loss are 9.4927GHz and -24.1196dB respectively. Fig. 9(b) gives the gain plot for antenna design two, it shows that for all values of ***phi*** the maximum gain is 3.8463dB at ***theta*** equals to 0 degrees. Fig. 9(c) gives the Axial Ratio Plot for the antenna design under consideration. Fig. 9(d) gives the axial ratio vs frequency plot for the antenna design.

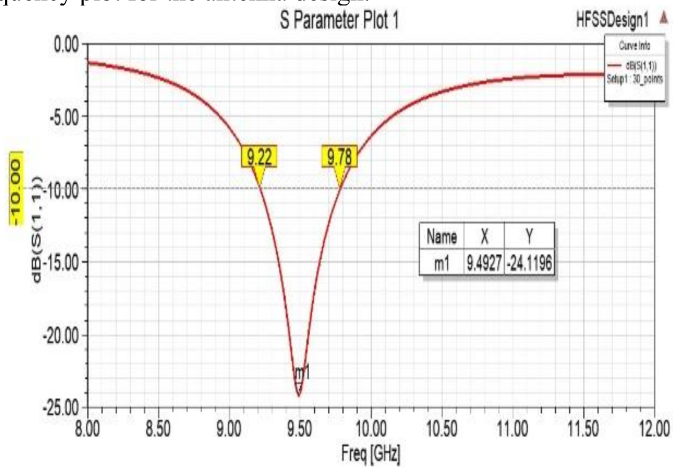


Fig 9 (a). Side view of final fabricated antenna

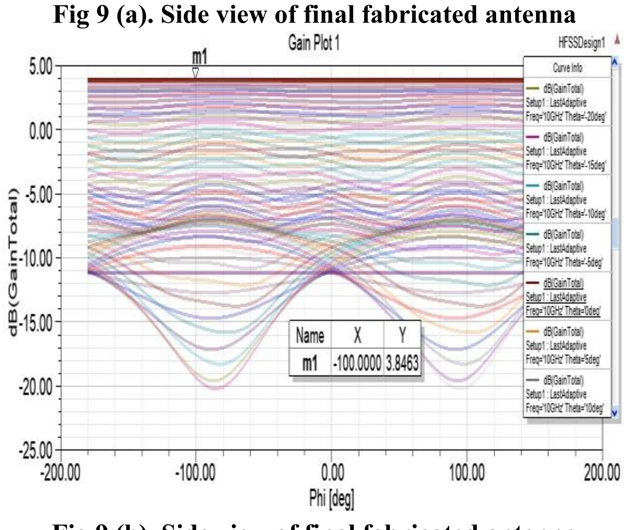


Fig 9 (b). Side view of final fabricated antenna

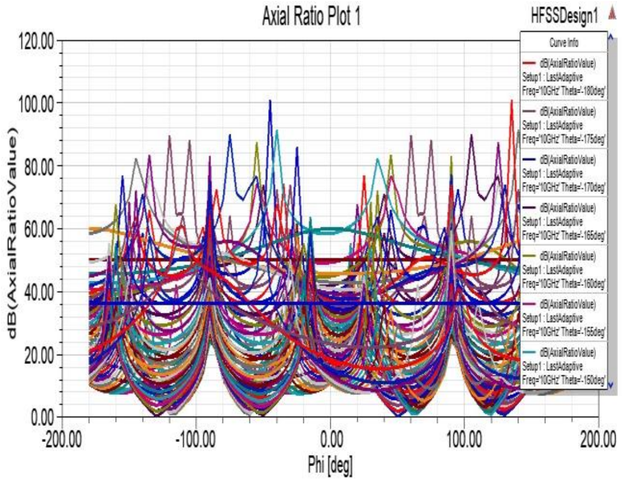


Fig 9 (c). Side view of final fabricated antenna

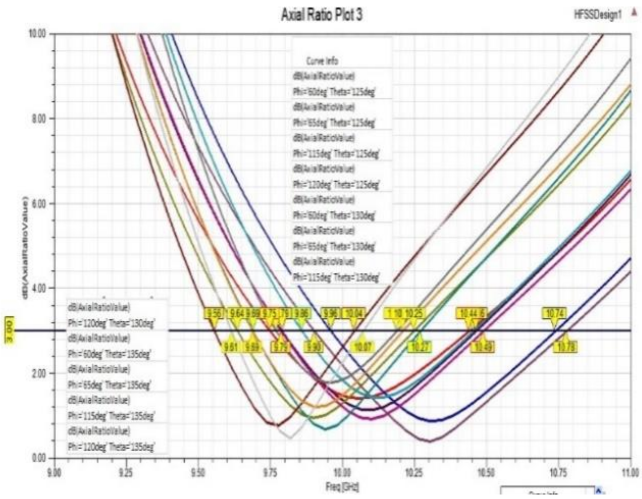


Fig 9 (d). Axial ratio vs frequency plot

C) Antenna Design 3: Simulation results for the third antenna design are shown in Fig. 10(a), 10(b) and 10(c). Bandwidth of the proposed antenna design there is 0.47GHz using the S parameter plot given in Fig. 10(a) for the frequency range 9.68GHz to 10.15 GHz. The values of the resonating frequency and return loss are 9.9066GHz and -47.0513dB respectively. Fig. 10(b) shows the gain plot for antenna design two, it's clear that for all values of ***phi*** the maximum gain is 2.5739dB at ***theta*** equals to 0 degrees. Fig. 10(c) gives the Axial Ratio Plot for the antenna design under consideration.

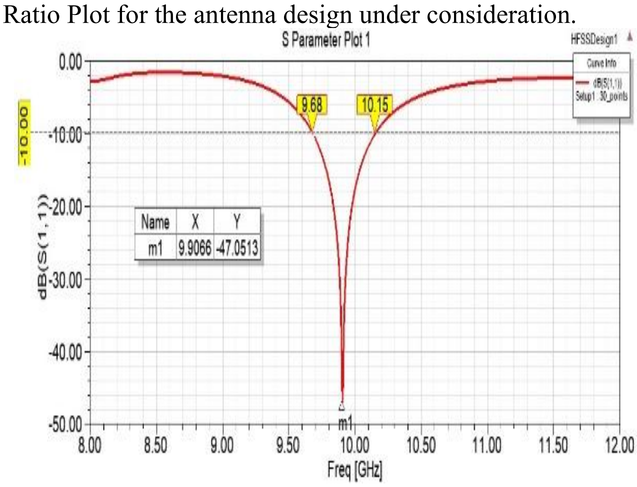


Fig 10 (a). Side view of final fabricated antenna

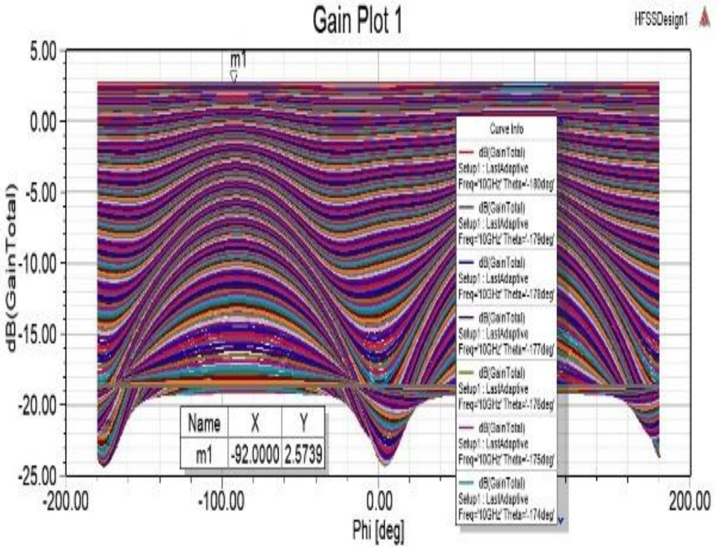


Fig 10 (b). Side view of final fabricated antenna

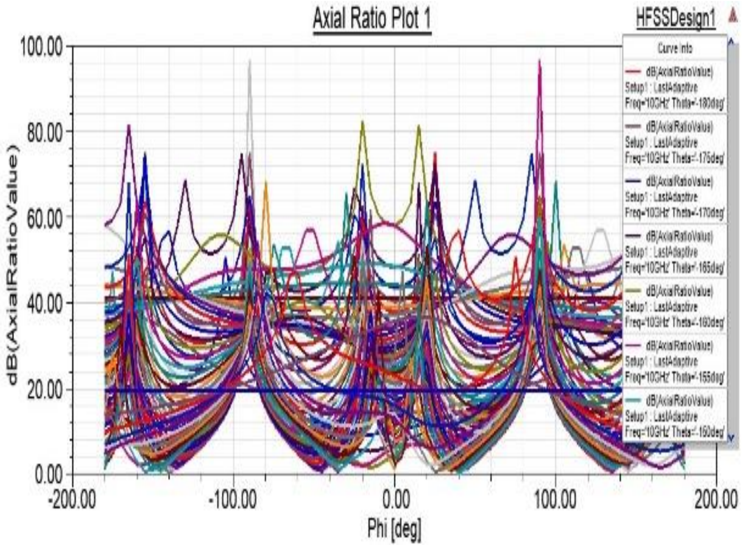


Fig 10 (c). Side view of final fabricated antenna

V. CONCLUSION

Three frequency and polarization reconfigurable rectangular patch antennas have been designed and analyzed. The first antenna is a simple rectangular microstrip patch antenna having a bandwidth of 0.56GHz, resonating frequency of 9.38GHz, return loss of-25.5038dB and a maximum gain of 4.0961dB. The second proposed antenna design has been derived from the basic structure of the first antenna by cutting four L-shaped slots at the four corners of the patch. On simulation it is found that for almost same bandwidth as of the first design the resonating frequency becomes 9.4927GHz, return loss becomes -24.1196dB, while the maximum gain drops to 3.8463dB. The final design i.e., the third design has been derived from the modification of second antenna design by cutting four L-shaped slots at the four corners of the ground. The slots have been cut in a way that they overlap with the slots of the patch. The simulation of this design having a bandwidth of 0.47GHz has a resonant frequency of 9.9066GHz, a return loss of -47.0513dB and the maximum gain reduces further to 2.5739dB. The proposed design is suitable for X band (8-12 GHz) applications like fixed and mobile satellite communication, RADAR engineering and X sub-bands applications for example in civil, military, and government institutions for weather monitoring, air traffic control, maritime vessel traffic control, defence tracking, and vehicle speed detection for law enforcement.

REFERENCES

[1] C. G. Christodoulou, Y. Tawk, S. A. Lane, and S. R. Erwin, "Reconfigurable Antennas for Wireless and Space Applications," *Proceedings of the IEEE*, vol. 100, no. 7, pp. 2250–2261, Jul. 2012, doi: 10.1109/JPROC.2012.2188249.

[2] L. Hinsz and B. D. Braaten, "A Frequency Reconfigurable Transmitter Antenna With Autonomous Switching Capabilities," *IEEE Trans Antennas Propag*, vol. 62, no. 7, pp. 3809–3813, Jul. 2014, doi: 10.1109/TAP.2014.2316298.

[3] X.-S. Yang, B.-Z. Wang, S. H. Yeung, Q. Xue, and K. F. Man, "Circularly Polarized Reconfigurable Crossed-Yagi Patch Antenna," *IEEE Antennas Propag Mag*, vol. 53, no. 5, pp. 65–80, Oct. 2011, doi: 10.1109/MAP.2011.6138429.

[4] Farha, "Reconfigurable Antenna Design with Frequency, Polarization and Pattern diversity," in *2019 Global Conference for Advancement in Technology (GCAT)*, IEEE, Oct. 2019, pp. 1–6. doi: 10.1109/GCAT47503.2019.8978345.

[5] Xue-Xia Yang, Bing-Cheng Shao, Fan Yang, A. Z. Elsherbeni, and Bo Gong, "A Polarization Reconfigurable Patch Antenna With Loop Slots on the Ground Plane," *IEEE Antennas Wirel Propag Lett*, vol. 11, pp. 69–72, 2012, doi: 10.1109/LAWP.2011.2182595.

[6] O. Siddiqui, W. U. H. Paul, S. Kirmani, M. Ahmad, D. Ali, and M. S. Ali, "Voltage and Frequency Control in a Microgrid," *Journal of Engineering Science and Technology Review*, vol. 15, no. 6, pp. 115–124, 2022, doi: 10.25103/jestr.156.14.

[7] W. U. H. Paul, A. S. Siddiqui, S. Kirmani, M. S. Ali, A. Ahmad, and Ibraheem, "Development of Strategies for the Optimal Rescheduling of the Household Load having RES Integration," *Tuijin Jishu/Journal of Propulsion Technology*, vol. 44, no. 3, pp. 3859–3867, 2022, doi: 10.52783/tjjpt.v44.i3.2145.

[8] M. S. Ali, A. Ahmad, Ibraheem, W. U. H. Paul, A. S. Siddiqui, and S. Kirmani, "Optimal Sizing and Placement of Energy Storage Systems in Hybrid Energy Environment," *Tuijin Jishu/Journal of Propulsion Technology*, vol. 44, no. 3, pp. 3147–3155, 2023, doi: 10.52783/tjjpt.v44.i3.1412.

[9] K. M. Mak, H. W. Lai, K. M. Luk, and K. L. Ho, "Polarization Reconfigurable Circular Patch Antenna With a C-Shaped," *IEEE Trans Antennas Propag*, vol. 65, no. 3, pp. 1388–1392, Mar. 2017, doi: 10.1109/TAP.2016.2640141.

[10] Y. J. Sung, T. U. Jang, and Y.-S. Kim, "A reconfigurable microstrip antenna for switchable polarization," *IEEE Microwave and Wireless Components Letters*, vol. 14, no. 11, pp. 534–536, Nov. 2004, doi: 10.1109/LMWC.2004.837061.

[11] D. Kumar, A. S. Siddiqui, H. P. Singh, and M. R. Tripathy, "Monopole Concept Based Frequency Reconfigurable Patch Antenna for mm-Wave 5G-Band Applications," in *2019 6th International Conference on Signal Processing and Integrated Networks (SPIN)*, IEEE, Mar. 2019, pp. 141–145. doi: 10.1109/SPIN.2019.8711649.

[12] A. Bhattacharya and R. Jyoti, "Frequency reconfigurable patch antenna using PIN diode at X-band," in *2015 IEEE 2nd International Conference on Recent Trends in Information Systems (ReTIS)*, IEEE, Jul. 2015, pp. 81–86. doi: 10.1109/ReTIS.2015.7232857.

[13] M. Lopes, M. N. Aik, and A. Dessai, "Design and Simulation of Frequency Reconfigurable Microstrip Patch Antenna for C band and X band Applications," in *2017 International Conference on Computing, Communication, Control and Automation (ICCUBEA)*, IEEE, Aug. 2017, pp. 1–6. doi: 10.1109/ICCUBEA.2017.8464009.

[14] K. Sharma *et al.*, "CPW-Fed UWB Reconfigurable Antenna (RF MEMS Switch) with X Band Applications," in *2018 6th Edition of International Conference on Wireless Networks & Embedded Systems (WECON)*, IEEE, Nov. 2018, pp. 37–40. doi: 10.1109/WECON.2018.8782047.

[15] W. U. H. Paul, A. S. Siddiqui, and S. Kirmani, "Intelligent Load Management System Development with Renewable Energy for Demand Side Management," *International Journal of Advanced Engineering and Management Research*, vol. 08, no. 02, pp. 140–153, 2023, doi: 10.51505/ijaemr.2023.8213.

[16] W. U. H. Paul, A. S. Siddiqui, and S. Kirmani, "Demand Side Management and Demand Response For Optimal Energy Usage: An Overview," *Paripex Indian Journal of Research*, pp. 151–152, Nov. 2022, doi: 10.36106/paripex/0608823.

[17] W. U. H. Paul, A. S. Siddiqui, and S. Kirmani, “Demand Side Management Strategies in Residential Load With Renewable Energy Integration: A Brief Overview,” *Paripex Indian Journal of Research*, vol. 11, no. 12, pp. 66–69, Dec. 2022, doi: 10.36106/paripex/3007742.

[18] W. U. H. Paul, A. S. Siddiqui, and S. Kirmani, “Optimal Positioning of Distributed Energy using Intelligent Hybrid Optimization,” *J Phys Conf Ser*, vol. 2570, no. 1, p. 012022, Aug. 2023, doi: 10.1088/1742-6596/2570/1/012022.

[19] I. Akhtar, W. U. H. Paul, S. Kirmani, and M. Asim, “Cost Analysis of 18 kW Solar Photovoltaic System for Smart Cities Growth in India,” in *Lecture Notes in Electrical Engineering*, 2021. doi: 10.1007/978-981-33-4080-0_63.

[20] M. Ahmad, D. Ali, W. U. H. Paul, M. S. Ali, and H. Ashfaq, “Management of Energy and Coordinated Control of PV/HESS in Islanded DC Microgrid,” in *Smart Energy and Advancement in Power Technologies*, vol. 1, Springer, Singapore, 2023, pp. 325–339. doi: 10.1007/978-981-19-4971-5_25.

[21] Md. S. Ali, A. Ahmad, W. U. H. Paul, D. Ali, and M. Ahmad, “Optimal Allocation of Wind-Based Distributed Generators in Power Distribution Systems Using Probabilistic Approach,” in *Smart Energy and Advancement in Power Technologies*, vol. 1, Springer Singapore, 2023, pp. 385–396. doi: 10.1007/978-981-19-4971-5_29.

[22] D. Ali, W. U. H. Paul, M. S. Ali, M. Ahmad, and H. Ashfaq, “Optimal Placement of Distribution Generation Sources in Hybrid Generation Network,” *Smart Grid and Renewable Energy*, vol. 12, no. 6, pp. 65–80, 2021, doi: 10.4236/sgre.2021.125005.

[23] S. Kirmani, W. U. H. Paul, M. B. Bhat, I. Akhtar, and A. S. Siddiqui, “Optimal Allocation of V2G Stations in a Microgrid Environment: Demand Response,” in *2023 International Conference on Power, Instrumentation, Energy and Control (PIECON)*, IEEE, Feb. 2023, pp. 1–6. doi: 10.1109/PIECON56912.2023.10085813.

[24] W. U. H. Paul, A. S. Siddiqui, and S. Kirmani, “Optimal Rescheduling for Transmission Congestion Management using Intelligent Hybrid Optimization,” in *Artificial Intelligence of Things*, Springer Nature Switzerland AG, 2024. doi: 10.1007/978-3-031-48781-1_12.

[25] M. U. Bashir, W. U. H. Paul, M. Ahmad, D. Ali, and Md. S. Ali, “An Efficient Hybrid TLBO-PSO Approach for Congestion Management Employing Real Power Generation Rescheduling,” *Smart Grid and Renewable Energy*, vol. 12, no. 08, pp. 113–135, 2021, doi: 10.4236/sgre.2021.128008.

[26] Jeen-Sheen Row and Jia-Fu Tsai, “Frequency-Reconfigurable Microstrip Patch Antennas With Circular Polarization,” *IEEE Antennas Wirel Propag Lett*, vol. 13, pp. 1112–1115, 2014, doi: 10.1109/LAWP.2014.2330293.

[27] W. U. H. Paul, S. Kirmani, M. B. Bhat, and S. A. Nahvi, “Data Based Controller Design for PMDC Motor Setup using System Identification,” *Studies in Indian Place Names*, vol. 40, no. 10, p. 11, 2020.

[28] Zi-Xian Yang, Hong-Chun Yang, Jing-Song Hong, and Yang Li, “Bandwidth Enhancement of a Polarization-Reconfigurable Patch Antenna With Stair-Slots on the Ground,” *IEEE Antennas Wirel Propag Lett*, vol. 13, pp. 579–582, 2014, doi: 10.1109/LAWP.2014.2312971.