Design of a combined horizontal and U slot patch antenna with reduced cross-polarization and increased sustainability

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Abstract. This paper presents a rectangular microstrip patch antenna designed to operate at a frequency of 2.6348 GHz. The antenna is equipped with a U-slot and horizontal slot to mitigate cross-polarization effectively. By strategically placing the U-slot on the radiating patch and incorporating a horizontal slot on the patch, the antenna achieves enhanced radiation characteristics. It demonstrates excellent impedance matching with a VSWR of 1.02, indicating minimal signal reflection (S11 of -27.47dB) and improved transmission efficiency with a gain of 7.11dBi. The proposed design offers reduced cross-polarization characteristics and increased sustainability with compact size, making it suitable for WLAN applications prioritizing reliable and efficient communication.

1 INTRODUCTION

Numerous industries use microstrip patch antennas extensively, including wireless communication systems, satellite communication, RFID systems, aerospace and defense, automotive technologies, medical devices, and Internet of Things applications. These antennas provide dependable wireless connectivity, tracking capabilities, and effective communication for various applications in a wide range of sectors to their compact size, low profile, and simple construction [1]. A microstrip patch antenna helps to reduce cross-polarisation through the selection of some factors such as substrate material, patch dimensions, feeding techniques, polarisation diversity, ground plane design, and impedance matching. By analyzing these factors together, we can minimize unwanted energy in the orthogonal polarisation and improve overall antenna performance[2].

It is well known that a U-shaped antenna arrangement has good frequency characteristics, which frequently results in good performance. The U-antenna's unique form helps it resonate at particular frequencies, resulting in effective radiation and receiving capabilities. U-shaped antennas are a good fit for dependable and high-quality communication applications because of their favourable frequency response[3]. The inset feeding method increases impedance matching, regulates radiation patterns, and improves

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performance in microstrip patch antennas. It benefits narrowband applications with a small design, precise feed control, and efficient power transmission[4].

The 2.4 GHz band is frequently used for Wireless LAN (WLAN) applications and includes a frequency of 2.6348 GHz. This frequency is widely used for wireless networking in consumer electronics, including routers, laptops, cell phones, and Internet of Things (IoT) devices[5].Microstrip patch slots can increase the gain by providing additional radiant elements and altering the current distribution on the antenna surface. The slots act as independent bright elements, contributing to the general radiation pattern and increasing the effective opening of the antenna. In addition, strategically placed slots can modify the current distribution, resulting in changes in the radiation pattern and improving the desired direction[6]. Since many antennas and optical systems are made to radiate electromagnetic waves across a restricted angle or in a single direction, directivity is a crucial measurement. An actual antenna's directivity can range from 1.76 dBi for a short dipole to 50 dBi for a considerable dish antenna[7]. As the highest radiating structure, the U-slot patch design is a strong contender to attain the maximum impedance bandwidth[8]. Slots decrease the return losses and improve the antenna's efficiency [9]. It is feasible to obtain a directed radiation pattern and broadside direction that is suitable for point-to-point transmission by constructing a rectangular slot in a microstrip patch antenna[10].

Due to the antenna's planar structure, the inset feeding method can be used to regulate the impedance. The inset gap and inset length, which regulate the behaviour of the antenna, are easily implementable and understandable. By using corner slots, the design of the antenna will become compact. It enhances the gain and shifts the resonating frequency to the intended values[11]. Symmetrical radiation and low cross-polarisation are attained by implementing balanced slots[12]. If the VSWR value is below 2 in an antenna, it leads to minimal power reflections, efficient power transfer, and optimal performance of the antenna system[13]. As the ground plane is composed of copper material, it acts as a radiating element and establishes a directional radiation pattern[14]. This frequency is widely used for wireless networking in consumer electronics, including routers, laptops, cell phones, and Internet of Things (IoT) devices[15].

Microstrip patch antennas can be developed and manufactured to work across a wide frequency range, from lower microwave bands to higher millimeter-wave frequencies. Because of their flexibility in frequency selection, they are suited for a wide range of communication applications, such as wireless LANs, satellite communication, radar systems, and point-to-point communication lines. Furthermore, through the modification of patch dimensions and adjustment of feeding procedures, it is possible to optimize their performance to meet specific frequency and bandwidth requirements [16-20].

DRA (Dielectric Resonator Antenna) exhibits high versatility, being operable across various frequency bands, including microwave and millimeter-wave ranges. Additionally, it can be customized to showcase specific radiation patterns and polarization characteristics [21]. Various IOT and network requirement based studies have been investigated [22-27] for the design requirement of a compact Antenna.

The rectangular microstrip patch antenna performed well at 2.6348 GHz with a gain of 7.11 dBi. The inclusion of slots to reduce cross-polarization has further enhanced its capabilities. The use of this antenna in numerous WLAN applications has a great deal of potential.

2 ANTENNA DESIGN

The antenna's design divides into three distinct parts: The first section involves creating a rectangular patch antenna, followed by incorporating U slots into the antenna's patch in the second section. In the final segment, we introduce horizontal slots to enhance performance. The intended operational frequency for the proposed antenna is precisely 2.6348 GHz.As illustrated in Fig. 1, the antenna comprises four parts: ground, patch, feed, and substrate. The ground and patch are made up of copper(annealed) material, and the dielectric constant of the substrate is 4.08. The proposed antenna is center fed by a microstrip line with a length of 24.9mm(fL) and a width of 2.98mm(fW). A 50 Ω microstrip line feed excites the rectangular slotted patch. The dimensions of the ground plane and substrate are equal, and the dimensions of the patch are 47mm x 30.2mm. Various feeding techniques include inset feed, microstrip line feed, coupled feed, and proximity coupled field. However, inset feeding is chosen as the best for this antenna, with testing indicating that the impedance is between 50 and 100 ohms.

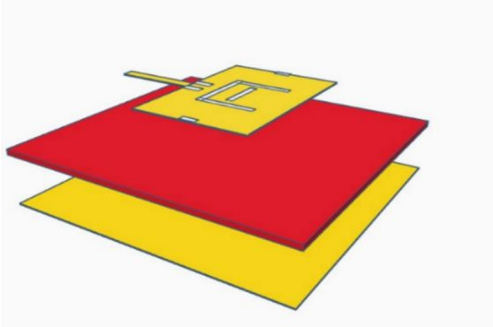

Fig.1. 3-D view of the antenna

All of the measurements Table 1 shows the length of the patch (Pl), the width of the patch (Pw), the length of the substrate (l), the width of the substrate (w), the height of the substrate (h), the length of the ground plane (Gl), and the width of the ground plane (Gw). When some sections of a patch antenna are etched away, the antenna transforms into a slotted antenna, as seen in Fig 2.

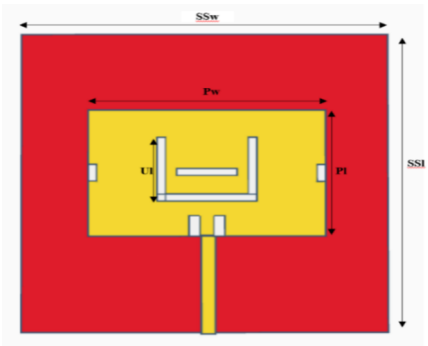

Fig.2.Front View of antenna

Firstly, the u-slot is implemented to broaden the impedance bandwidth of the antenna. The U-slot can inhibit surface wave excitation, reducing the impact of undesirable modes and improving overall antenna performance. Horizontal slots are implemented to reduce the return losses and to increase the directivity. As the slots on the patch are positioned

symmetrically, radiation also emits symmetrically. It contributes to increasing the bandwidth of the microstrip patch antenna by producing additional resonance. Table 1 shows the final dimensions of the slots. Cross-polarisation and return loss are considered in determining the optimal dimensions for the slot, and a parametric analysis is performed.

TABLE I. Antenna Dimensions

Parameter	Dimensions (in mm)
Pl	30.2
Pw	47
Pt	1.535
SSL	80
SSw	80
St	1.5
Gl	80
Gw	80
GT	0.035
Ul	14
Hl	1
Sw	2

The design formula for the antenna is given in Eq(1).

$$f = \frac{c}{2L\sqrt{\epsilon}} \quad (1)$$

3. RESULTS AND DISCUSSION

3.1 Parametric Results

The process of analyzing output values by providing numerous diverse inputs is known as parametric analysis. In this paper, the parameters Ul, Hl, and Sw are parametrically analyzed to determine the optimum outcome in terms of the best return loss obtained, radiation pattern, cross polarisation, and gain of the antenna. The parametric analysis of the Dimension Ul is displayed in Fig 1 where the dimensions in the Ul are taken from 7m m to 15mm. As there is an increment in the parameter value, the frequency shift is changing towards the left side as well as the return loss is also decreasing hence we select the value at 9.

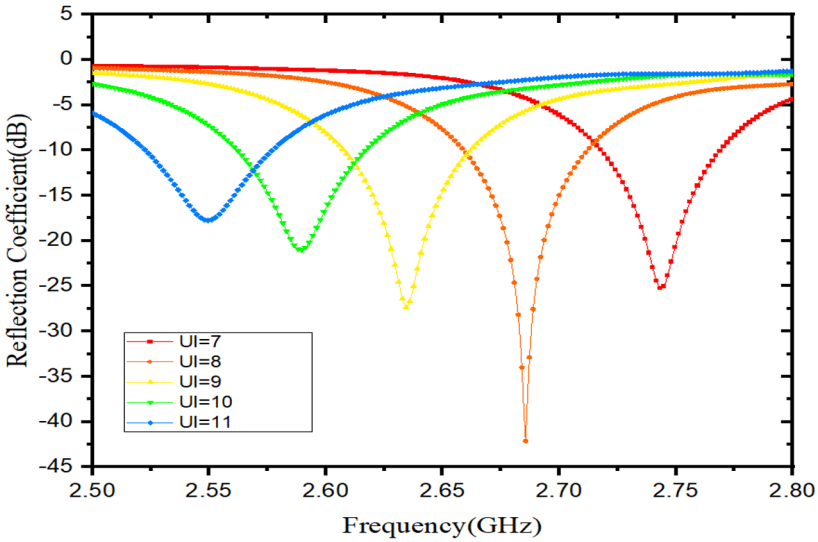

Fig.3.Parametric Analysis of Ul

In Fig. 4. The length of the side HI is kept under parameter sweep, which does not affect the resonating frequency.

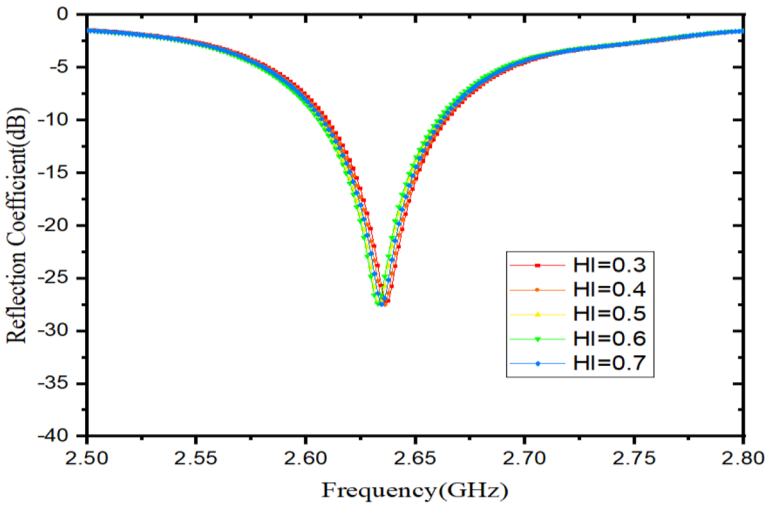

Fig.4.Parametric Analysis of sw

Fig. 5 depicts the parametric analysis of the Dimension SW, where the dimensions in the SW range from 19.5m m to 23.5mm. The frequency shift is shifting to the right when the parameter value is increased.

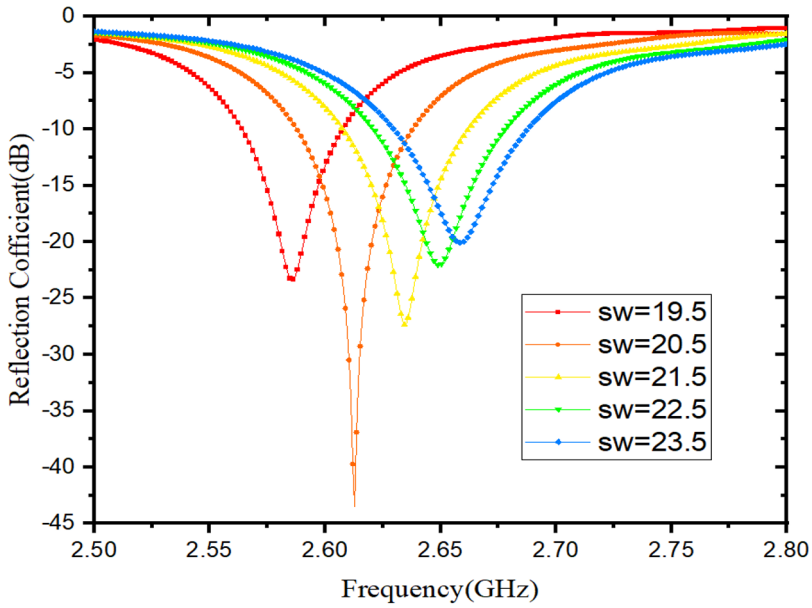

Fig.5.Parametric Analysis of sw

Fig.6. shows the S11 parameter graph of the proposed Microstrip Patch Antenna between the resonating frequency and the reflection coefficient of the single Microstrip Patch Antenna. The Graph is taken from the range of frequencies 2.2 GHz to 2.8 GHz and the reflection Coefficient of the antenna is lowest at the frequency 2.6348 GHz. The return loss is -27.47 dB. The proposed antenna works in the range of frequencies 2.6628 GHz – 2.6078 GHz having a bandwidth of 0.005 GHz

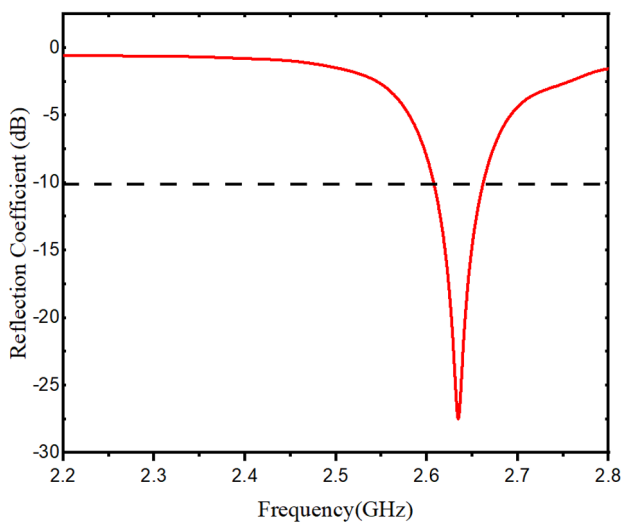

Fig.6. S11(dB)

Fig 7. Co-polarization in antennas refers to coordinating their polarisation orientations for the strongest and clearest signal transmission. Compared to an isotropic antenna, an antenna with a gain of 3.09 dBi is better at focusing its signal in a single direction. When the polarisation orientations of the transmitting and receiving antennas are perpendicular to one another, this is referred to as cross-polarization in antennas. The measurement "-11.6 dBi" probably refers to the antenna's gain in a particular direction.

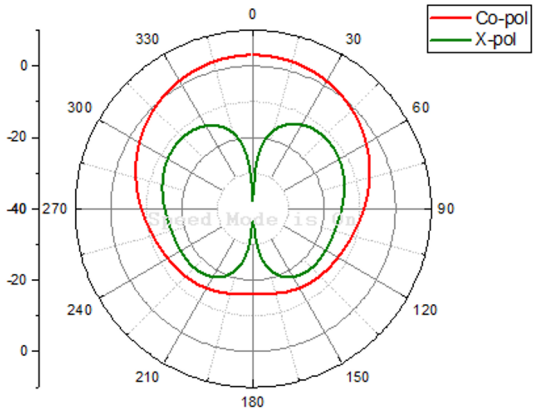

Fig. 7. Polar Plot at frequency 2.6348 GHz

3.2 Surface Currents

Surface currents are currents that move over a conducting material's surface, such as the surface of an antenna. An antenna experiences an electric current flow when an electromagnetic wave, such as a radio wave, interacts with it. The electromagnetic signals are sent or received by this surface current. The form, dimensions, and configuration of the conductive components on an antenna determine how the surface currents will move. Various antenna configurations are employed for different purposes, such as dipole antennas, loop antennas, patch antennas, and others. Each configuration maximizes the interplay between the surface currents and the electromagnetic waves. In our slot antenna, the maximum current flows at the tip of the u slot and it creates specific current paths and impacts the impedance characteristics of the antenna

3.3 Radiation Pattern

Half-power beam width (HPBW) of 79.8 degrees is achieved. This indicates that the antenna's main lobe radiates over an angle of 79.8 degrees, with the majority of its energy being focused inside this angular region during transmission or reception. As HPBW is small, which means that the antenna focuses its energy on a narrower beam.

The radiation pattern is a graph displaying how the antenna's signal intensity changes with direction. A 79.8 degree HPBW would have its main lobe covered at about a 79.8-degree wide angle, and the energy outside of this range would be greatly reduced. When a strong, focused signal must go farther, antennas with narrower HPBW are appropriate for point-to-point transmission.

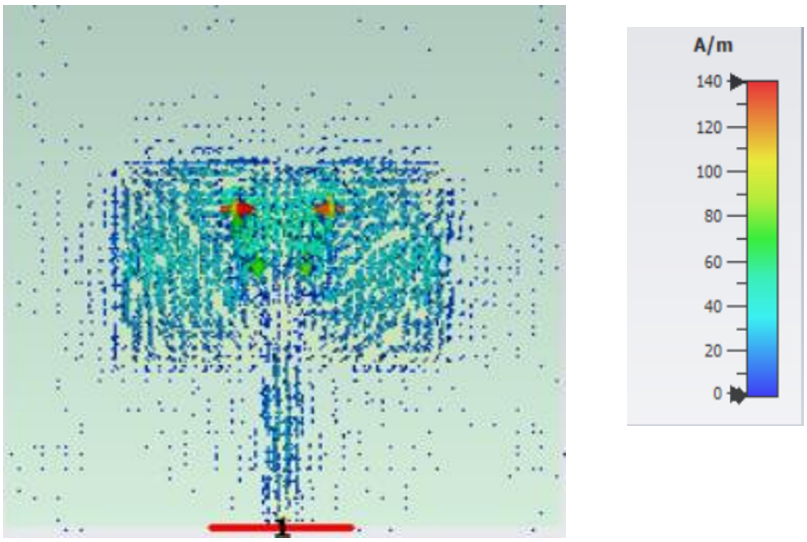

Fig.8.SURFACE CURRENT

The energy transmitted outside the 79.8-degree angle is limited, reducing signal wastage in undesired directions. A narrow radiation pattern can lessen some of the consequences of signal deterioration brought on by precipitation, snow, or other atmospheric elements.

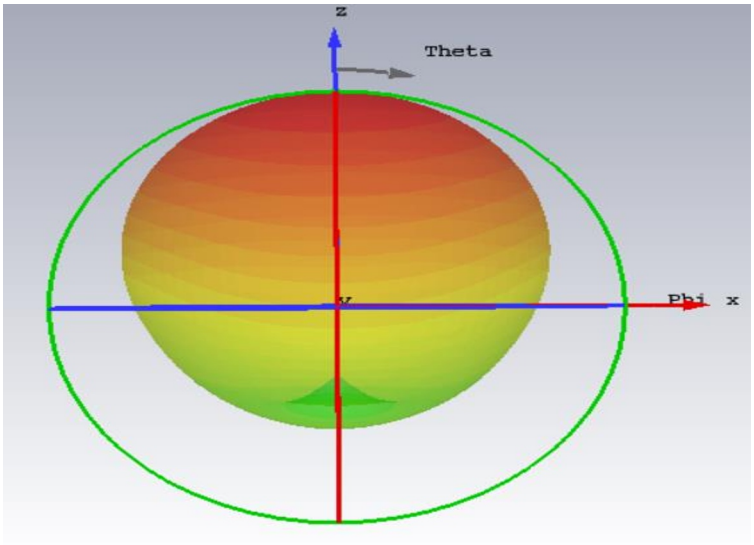

Fig. 10. 3-D Radiation Pattern of Antenna

4 CONCLUSION

At 2.6348 GHz the rectangular microstrip patch antenna has shown good performance with a return loss of -28.782 dB at the operational frequency. It has excellent impedance matching with a VSWR of 1.02 and minimal signal reflection (S11 of 27.47-dB). Its capabilities have

been improved even more by the addition of slots to lessen cross-polarization. The proposed antenna operates at frequencies ranging from 2.6078 GHz to 2.6 GHz and has a bandwidth of 0.005 GHz. This antenna is sustainable and has enormous potential for use in a wide range of WLAN applications.

References

1.Buket Kul,Taha Imeci. "L, U, T, and F-Shaped Slots in Patch Antenna*", IEEE,2017*

2. Abhijyoti Ghosh, Dia Ghosh, Sudipta Chattopadhyay, "Rectangular Microstrip Antenna on Slot-Type Defected Ground for Reduced Cross-Polarized Radiation*", IEEE,2015*

3.J. A. Ansari, Nagendra Prasad Yadav, Anurag Mishra, "Broadband Rectangular Microstrip Antenna Loaded with a Pair of U-Shaped Slot*", IEEE,2010*

4. Mohit Mohat, Asmita Rajawat, Sindhu Hak Gupta, "Design of an Inset- Fed Slotted Triple Band Antenna*", IEEE,2018*

5. Ajay Kumar Sharma, B.V.R Reddy, Ashok Mittal, "Slot Loaded Microstrip Patch Antenna for WLAN and WiMAX Applications*", IEEE,2015*

6.M. S. Rabbani* and H. Ghafouri-Shiraz, "Evaluation of Gain Enhancement in Large Microstrip antenna arrays for MM-wave applications*", IEEE,2017*

7. Kengo Okada, Kouhei Kasagi, Naoto Oshima, "Resonant-Tunneling-Diode Terahertz Oscillator Using Patch Antenna Integrated on Slot Resonator for Power Radiation*", IEEE,2015*

8. Ali Ramadan, Mohammed Al-Husseini, "A Directional Polarization Reconfigurable Microstrip Antenna*", IEEE*,2011

9.M. Z. A. Abd Aziz1, Z. Zakaria, "Investigation of dual and Meander Triple slot microstrip patch antenna*", IEEE,*2013

10. Huaxiao Lu, Fang Liu, "Single-Layer Single-Patch Wideband Dual-Beam E-Shaped Patch Antenna", *IEEE*,2017

11. Sundaravel Elumalai Muthumani, Vallikannu*, "*Compact Slot Loaded Koch Fractal Microstrip Patch Antenna*"*, *IEEE*,2013

12.Mahdi Moosazadeh and Sergey Kharkovsky. "Compact and Small Planar Monopole Antenna With Symmetrical L- and U-Shaped Slots for WLAN/WiMAX Applications*"*, *IEEE*,2014

13. S.T. Fan, Y.Z. Yin, B. Lee, "Bandwidth Enhancement of a Printed Slot Antenna with a Pair of Parasitic Patches*", IEEE*,2012

14.Marno van Rooyen, Johann W. Odendaal, "High Gain Directional Antenna for WLAN and WiMA*X* Application*s"*,IEEE,2017

15. Praveen Kumar Rao, KM Jyoti Singh, Rajan Mishra, "A Circular Shaped Microstrip patch Antenna for Bluetooth/Wi-Fi/UWB/X-band Applications*", IEEE,2018*

16. Ushasree, A., Agarwal, V. *"*Applications Metamaterial Loaded Endfire Circularly Polarized High-Gain Microstrip Patch Antenna for L Band Frequency". Iran J Sci Technol Trans Electr Eng 46, 873–882 (2022)

17. Ushasree, A., and Vipul Agarwal. "Pentaband Dual-Polarized Antenna for Multiservice Wireless Applications*." Computation* 11.4 (2023)

18.Bagade Shilpa,L. Koteswara Rao,N. Arun Vignesh and Vadladi Vijaya Kumar *"Design of inset fed circular dual-band patch antenna for WLAN frequencies."* International Journal of Systems, Control, and Communications (2022)

19. N. R. P. S. Krishna, H. Shirisha, A. M. H. Isfahani and K. Manisha, "Design of Dual Rectangular Slotted MicroStrip Patch Antenna for S-Band," *2023 4th International Conference for Emerging Technology (INCET)*, Belgaum, India, 2023

20. M. Siripuram, N. Nagula, A. Muddapuram and M. Kumari, "Design of a H-slot Based Microstrip Patch Antenna," *2023 4th International Conference for Emerging Technology (INCET)*, Belgaum, India, 2023

21. Kumari M., Rao, T.V., Jayakar, S.A., Srinivas, D., Padhan, D.G., Reddy, A.K., Reddy, P.R. and Tura, A.D., 2022. "*A* Beam Steering Dielectric Resonator Antenna Designed Using Rogers RO4003C Material for S-Band Applications*"*. Advances in Materials Science and Engineering, 2022.

22. Swamy, T.J., Murthy, T.N."ESmart: An IoT based Intelligent Health Monitoring and Management System for Mankind",International Conference on Computer Communication and Informatics, ICCCI 2019

23.Atul, D.J., Kamalraj, R., Ramesh, G., Sakthidasan Sankaran, K., Sharma, S., Khasim, S."A machine learning based IoT for providing an intrusion detection system for security, Microprocessors and Microsystems 2021

24. Dharmadhikari, S.C., Gampala, V., Rao, C.M., Khasim, S., Jain, S., Bhaskaran, R."A smart grid incorporated with ML and IoT for a secure management system", Microprocessors and Microsystem, 2021

25. Reddy, V.M., Hamsalekha, S., Reddy, V.S,"An IoT enabled real-time monitoring system for automatic curing and early age strength monitoring of concrete" AIP Conference Proceedings (2021)

26. P., Meenakshi, K., Swaraja, K., Rajani, A., Raju, M.S. "EEG based interpretation of human brain activity during yoga and meditation using machine learning: A systematic review",Complementary Therapies in Clinical Practice 2019

27. Nayak, P., Sinha, P."Analysis of random way point and random walk mobility model for reactive routing protocols for MANET using netsim simulator Proceedings - AIMS 5, 3rd International Conference on Artificial Intelligence, Modelling and Simulation 2015.