Design and Analysis of a Compact Dual-Band Antenna for Wi-Max, C, and X- Band Applications

Ravi Mali*[1], Rajkumar Jatav[1], Praveen Singh Rathore[1], and Rupam Bharati[1]

[1] *Department of Electronics Engineering Indian Institute of Technology (BHU), Varanasi, UP (221005)*
*[*1]ravi.jrf.ece22@itbhu.ac.in*

Abstract. This paper presents a design of a compact-size dual-band antenna for Wi-Max, C, and X-band applications. The modified symmetrical step-sized slit is etched on the coplanar waveguide (CPW) ground plane. The radiating patch and CPW ground plane are designed on a 1.6 mm thick FR4 dielectric constant ε_r=4.4 and tanδ =0.02 with a compact size of 10×10 mm^2. The antenna is designed to operate in dual-band. The Wi-Max band (5.2 GHz) is obtained by etching a split ring on the rectangular microstrip patch. The operating bandwidth is obtained from 5.22 GHz-5.38 GHz (3.72 %) and 7.28-8.48 GHz (15.22 %). It has a maximum gain of 2.1 dBi at 7.9 GHz and radiation efficiency above 95%. The Co and cross-polarization level is -45 dB and -32 dB in E and H-plane at 5.3 GHz and -40 dB and -28 dB at 7.9 GHz, respectively.

Keywords: C/X-band, Dual Band Split ring, Step size slit, Wi-Max.

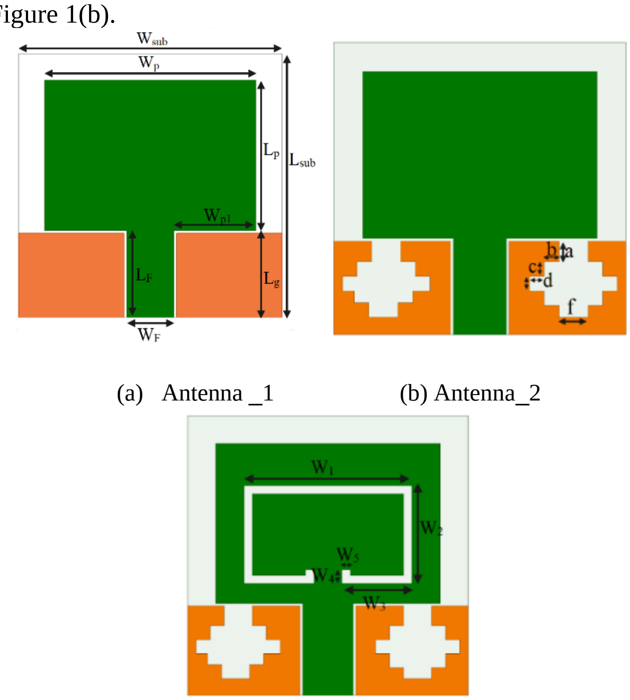
1. Introduction

The demand for compact size and low-profile antenna has grown over the last few decades because the number of electronic devices has increased, such as satellite, mobile, and wireless devices. This type of device is possible by creating multiple operating bands in a single antenna structure. These devices communicate over the operating band of GSM-850/900/1800/1900, UMTS (824-894), LTE2300(2300-2400 MHz), LTE2500(2500-2690 MHz), Bluetooth (2.4 GHz), Wi-max (3.1/5.3 GHz), WLAN (5.8 GHz) [1]. Antenna designers have many challenges in introducing such type of planar antenna. Over the last few decades, researchers have reported several applications and techniques for multiband operation. The multiband characteristics are obtained by etching the number of slit/slot/notches and embedding stubs on the radiating patch and ground plane. Several kinds of literature have been available in the last few decades on multiband antenna design, such as a rectangular patch with extended dimensions that provided a dual operating band for C and X-band applications [2]. Dual-band and UWB (ultra-wideband) were achieved by a strip loop and slot loop [3,4], dual-band achieved by multilayer structure [5], parasitic patch [6], and inverted PIFA antenna [6], Second resonance is created by current distribution on the non-radiating edge [7,8]. The previous literature provides the C and X Band antenna for satellite and military applications [9,10,11,12,13,14,15]. However, it is very challenging to obtain a lower frequency with a small-sized antenna.

For the same perspectives in this paper, two resonances are generated by etching modified symmetrical step-sized slits on a ground plane and a split ring on the radiating patch. The C and X-bands are obtained by etching symmetrical slots on the CPW ground plane. The second resonance for Wi-Max is created by introducing a split ring on the radiating patch by perturbing the surface current. The proposed antenna structure has a compact size, low profile, and good polarization purity for satellite application. The geometrical configuration is described in section 2. The reflection coefficient for various stages, radiation pattern, gain, and efficiency are compared in section 3.

2. Design Methodology

The geometrical configuration of the proposed antenna structure is shown in Figure 1(a), (b), and (c). It consists of FR-4 epoxy substrate with dielectric constant ε_r= 4.4 and loss tangent tanδ =0.02. The thickness of the substrate is 1.6 mm. The overall volume of this proposed antenna is 10 ×10×1. 6 mm^3. Figure 1(a) shows a rectangular patch antenna with a partial CPW ground plane. Modified symmetrical step-sized slits are etched on the CPW ground plane and are depicted in Figure 1(b).



(a) Antenna _1 (b) Antenna_2

(c) Antenna_3

Fig. 1. Design stage of the proposed antenna (a) Antenna_1, (b) Antenna_2, (c) Antenna_3.

DOI: http://dx.doi.org/10.32452/IJAMT.2023.301305 © 2023 IJAMT

In Figure 1(c), Antenna_3 has modified symmetrical step-sized slits on the CPW ground plane and a split ring on the radiating patch. This proposed antenna is simulated on High-Frequency Structure Simulator (HFSS) software [12]. The size of the rectangular patch is 8×5.7 mm^2. The total length of the ground step-sized slit is 12 mm (4× (a +b +c +d +e)). The size of the split ring is 34.6 mm (W_1+W_2+W_3+(2×W_4) +(2×W_5)). The optimized dimensions of the proposed antenna are listed in Table 1.

3. Results

All three proposed antenna stages are simulated, and dimensions are optimized using the HFSS simulation tool. In this work, our goal is to design a small size (10×10) mm^2, dual-band antenna for Wi-Max, C, and X-band applications.

The simulated *S*-Parameter of the proposed design stages is shown in Figure 2. The resonance at 7.8 GHz is due to a modified step-sized slit and provides a C/X band. This band covers the uplink frequency of the C-band from 7.07-8.0 GHz and the downlink frequency of the X-band from 8.0 GHz-8.40 GHz. It is observed in Antenna_1, there is no resonance exists. While Antenna_2 covers C and X-band. The comparison results are displayed in Figure 2 for both antennas. Again, to focus on creating a second resonance for the Wi-Max application, a split ring slot is etched on the radiating structure by analyzing the surface current distribution. The total length of this split ring is 20 mm is approximately equal to half of the wavelength for 5.38 GHz. This structure provides the operating band from 5.22 GHz to 5.38 GHz at a resonance of 5.3 GHz. The second band is from 7.28 - 8.45 GHz. From Figure 2, it is observed that Antenna_3 provides the dual-band for Wi-max and C-X Band. The simulated Co- and Cross-polarization in E-plane (XY-Plane) and H-plane (YZ-plane) are shown in Figure 3. It is observed that the omnidirectional radiation pattern is achieved at 7.8 GHz for Antenna_2. The cross-polarization level in E-plane is less than -30 dB. The cross-polarization level in H-plane is -20dB. The gain and efficiency plot for proposed Antenna_2 is depicted in Figure 4. It is observed that the gain is stable in the overall operating frequency band which is 2.1 dBi. The total radiation efficiency is above 95 % in the operating band.

Table 1: Optimized dimension of the proposed antenna.

Parameter	Value (mm)	Parameter	Value (mm)
W_{sub}	10	b	0.5
L_{sub}	10	c	0.5
H_{sub}	1.6	d	0.5
W_p	8	e	0.5
Lp	5.7	W_1	6
W_{p1}	3.1	W_2	3.5
L_F	3.3	W3	2.5
W_F	1.8	W4	0.5
Lg	3.2	W_5	0.5
a	0.7	G_{ap}	0.1

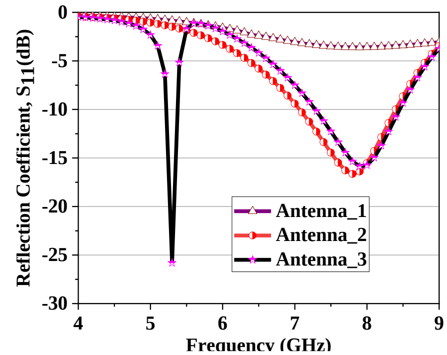
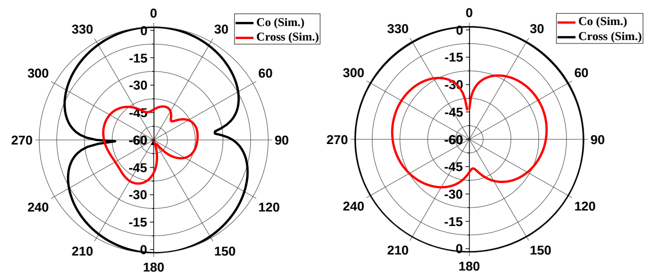


Fig. 2. Simulated *S*-parameter for the proposed design stages.



(a) (b)

Fig.3. Simulated Co-and Cross Polarization for proposed antenna_2.at 7.8 GHz (a) XY-plane (E-plane); (b) YZ-Plane (H-plane).

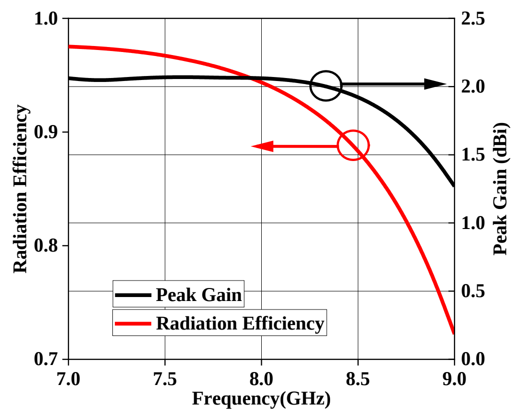
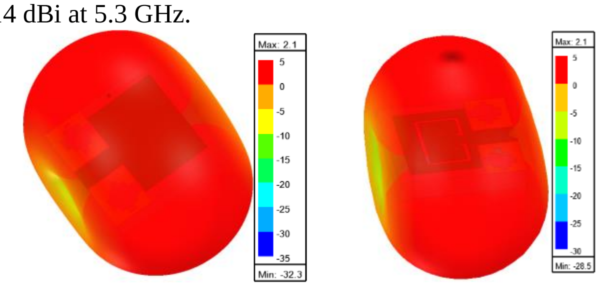


Fig. 4. Simulated Gain and Radiation pattern for proposed antenna2.

The 3-D radiation patterns of proposed Antenna_2 and Antenna_3 are presented in Figure 5. The total gain of both antennas in the C/X band at 7.8 GHz and 7.9 GHz is 2.1 dBi. The 3-D radiation pattern for antenna_3 is presented at 5.3 GHz is shown in Figure 6. The total gain of the antenna is 0.14 dBi at 5.3 GHz.



(a) 7.8 GHz (b) 7.9 GHz

Fig. 5. Simulated 3-D Radiation Pattern (a) 7.8 GHz for Antenna_2 (b) 7.9 GHz for Antenna_3.

DOI: http://dx.doi.org/10.32452/IJAMT.2023.301305 © 2023 IJAMT

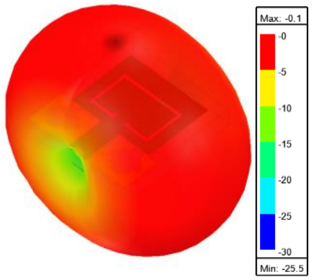


Fig. 6. 3-D Radiation pattern for antenna_3 at 5.3 GHz.

In Figure 7, the simulated radiation patterns at 5.3 GHz and 7.9 GHz are presented. From Figures 7(a) and 7(b), it is observed that in the E-plane (XY-plane), the radiation pattern is bidirectional, while in H-plane (YZ-Plane) the radiation pattern is omnidirectional. The proposed antenna provides good polarization purity. The cross-polarization level in E-plane is -45dB, while in H-plane, the cross-polarization level is -32 dB. Figures 7(c) and 7(d) show the cross-polarization level at 7.9 GHz. It is observed that the radiation pattern is bidirectional in E-plane and omnidirectional in H-plane. The co and cross-polarization level is -40 dB and -28 dB. The surface current distribution for Antenna_1 is displayed in Figure 8(a). It is observed that in Antenna_1 the surface current is distributed along the edge of the feed line, which means the mismatch of the impedance of the feed line to the radiating patch. There are no surface current flows on the radiating patch, and there is no radiation.

From Figure 8(a) it is observed that, the maximum surface impedance is on the ground plane, so that a modified step-sized slit with half of the wavelength ($\lambda_L/2$) is etched on the ground plane. In Figure 8(b) the surface current ensures that a resonance at frequency 7.9 GHz is obtained for a modified step-sized slit on both sides of the ground plane.

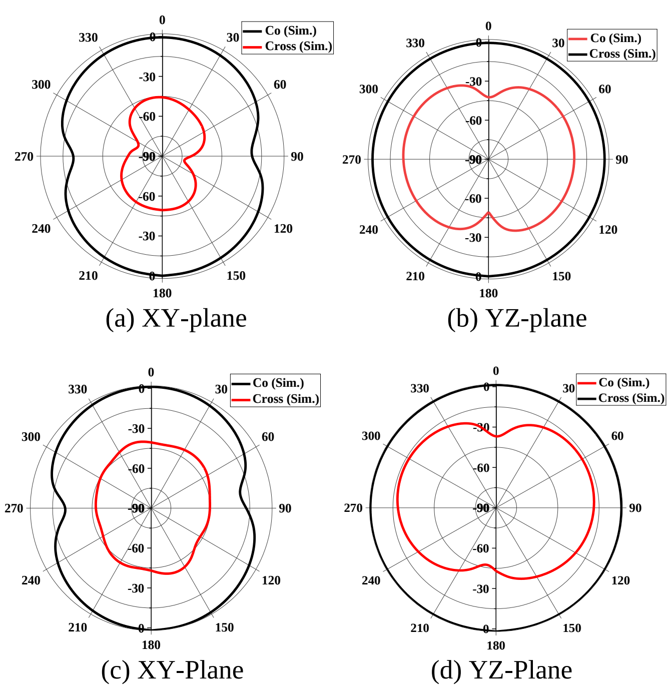


Fig. 7. Simulated Radiation Pattern for Antenna_3 at 5.3 GHz (a, b) and 7.9 GHz (c, d).

The operating band is obtained from 7.07–8.40 GHz. It is observed that the maximum surface current is distributed on the edge of the slit, which confirms that the resonating band is created by etching the slit on the CPW ground plane. The slit length is calculated using Eqs (1) and (2).

$$Slit_{Lenth} = 4 \times (a + b + c + d + e/2) + f$$

$$Slit_{Lenth} = 4 \times (0.7 + 3 \times 0.5) + 0.25) + 1\ mm$$

$$Slit_{Lenth} = 10.8\ mm$$

$$Total\ Slit_{Length} = 2 \times Slit_{Lenth}$$

$$Total\ Slit_{Length} = 21.6\ mm = \frac{\lambda_L}{2} \quad \dots (1)$$

$$\lambda_L = \frac{c}{f_L} = 42.43\ mm \quad \dots .(2)$$

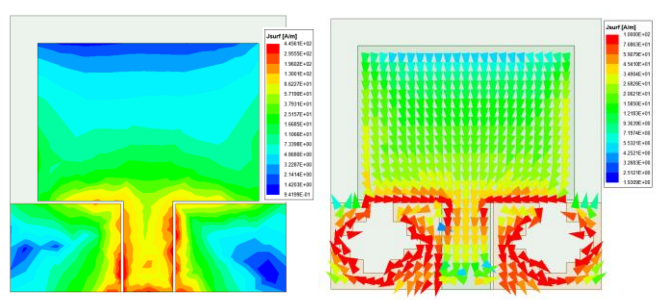
From Eqs (1) and (2), it is observed that the slot length is equal to half of the wavelength ($\lambda_L/2$) at 7.07 GHz. This equation is verified by displaying the surface current distribution at 7.9 GHz depicted in Figure 8 (b). From Figure 8(c) the desired band 5.22 GHz to 5.38 GHz is achieved by etching a split ring on the rectangular radiator. The split ring length and position are taken by displaying the surface current distribution on Antenna_1. The length of the split ring is 34.6 mm for 5.3 GHz resonance follows Eqs (3), (4).

$$Split\ ring_{Lenth} = 34.6\ mm \quad \dots .(3)$$

$$\lambda_{L1} = \frac{c}{f_{L1}} = 56.60\ mm \quad \dots .(4)$$

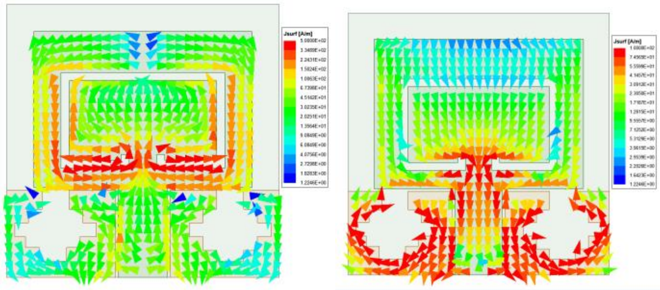
From Eqs (3) and (4), it is observed that the split ring length is 34.6 mm which is equal to half of the wavelength $\lambda_{L1}/2$. Figure 8(c) shows that the vector surface current is distributed along the split ring on the rectangular patch, which confirms the cause of creating a resonance at 5.3 GHz.

Figure 8 (d) displays the vector surface current distribution for Antenna_3 at 7.9 GHz. The simulated gain and radiation efficiency plot versus frequency are displayed in Figure 9 (a) and (b) for Wi-MAX Band and C-X Band, respectively. From Figure 9 (a), Antenna_3 in Wi-MAX Band has 0.14 dBi gain and above 59% radiation efficiency. Figure 9(b) shows that 2.1dBi gain and above 95% for Antenna_3 in the C-X band. Table 2 listed the comparison results of previously reported structures for single and dual-band antennas. It shows that the designed antenna has a compact size with dual-band characteristics compared with previously reported work.



(a) Antenna_1 at 7.8 GHz (b) Antenna_2 at 7.9 GHz

DOI: http://dx.doi.org/10.32452/IJAMT.2023.301305

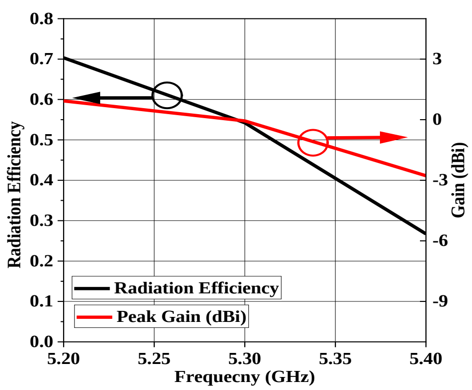


(c) Antenna_3 at 5.3 GHz (d) Antenna_3 at 7.9 GHz

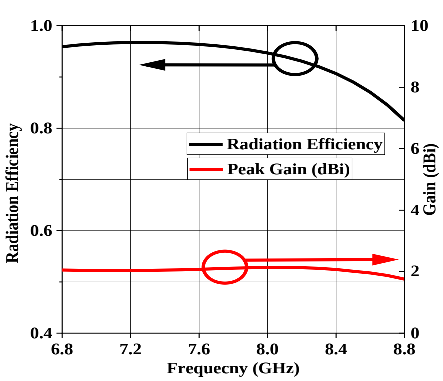
Fig. 8. Surface current distribution for (a) Antenna_1 (b) 7.9 GHz and (c) 5.3 GHz for Antenna_2 (d) Anteenn_3 at 7.9 GHz.

Table 2: Comparison table with an existing structure.

Reference	Size (mm^3)	Working Band
[2]	58×65×1.6	Dual-Band
[3]	45 × 15 × 0.813	Dual Band
[14]	25× 28× 1.6	Dual-band
[15]	250 × 200 × 2.2	Tri-Band
[17]	24.5 ×20 ×1.6	Dual-band
[18]	20×35×0.8	Dual Band
[18]	31× 40 ×1.6	Single Band
This work	10×10×1.6	Dual Band



(a)



(b)

Fig. 9. Simulated gain and radiation efficiency for antenna_3 (a) Wi-Max (b) C-X-Band

4. Conclusion

In this article design of a compact-size dual-band antenna for Wi-MAX and C-X- Band, applications is proposed. The first operating band for C-X is created by etching a symmetrical modified step-size slit on the CPW ground plane. It covers uplink and downlink frequency for C and X-band satellite applications. The peak gain of 2.1 dBi is obtained. Another band for Wi-MAX is created by etching a split ring on the rectangular patch. This proposed antenna has good polarization purity at 5.3 GHz and 7.9 GHz. The cross-polarization level is below -45 dB obtained at 5.3 GHz, this band is applicable and has acceptable value for Wi-max applications. The cross-polarization level is -40 dB at 7.9 GHz. It is applicable for uplink satellite applications. This proposed structure has a small size of 10×10 mm^2 and is suitable for Wi-Max, satellite, surveillance, and weather radar system. The lower X-Band is used for downlink satellite and military, traffic control, tracking system, and vehicle speed detection applications.

References

[1] Ren. X.S., Y.Z. Yin, W. Hu, and Y.-Q. Wei, Compact triband rectangular ring patch antenna with asymmetrical strips for WLAN/WiMAX applications, *Journal of Electromagnetic Waves and Applications*, vol. 24, no. 13, pp.1829–1838, 2010.

[2] Sharma R and M. Kumar, Dual band microstrip antenna for C- and X band wireless applications, *IMPACT-Aligarh, India*, pp. 154-158, 2013.

[3] M K. Mandal, Z. N. Chen, Compact dual-band and ultrawideband loop antennas, *IEEE Transactions on Antennas and Propagation*, vol. 59, pp. 2774-2779, 2011.

[4] Mukandatimana, T. A. Denidni, and L. Talbi, Design of a new dual-band CPW-fed slot antenna for ISM applications, *IEEE 59th Vehicular Technology Conference. VTC 2004-Spring (IEEE Cat. No.04CH37514)*,vol.1, pp. 6-9, 2004.

[5] J.H. Lu, Single-feed dual-frequency slotted microstrip antenna with pair of step-slots, *Electronics Letters*, vol. 35, pp. 354-355, 1999.

[6] S.T Fang and K.L. Wong, A dual-frequency equilateral-triangular microstrip antenna with a pair of narrow slots, *Microwave Optical Technology Letters*, vol. 23, pp. 82-84,1999.

[7] Wen-Shyang Chen, Tzung-Wen Chiou and Kin-Lu Wong, Compact PIFA for GSM/DCS/PCS Triple-Band Mobile Phone, *IEEE Antennas Propagation Society International Symposium*, vol.4, pp. 528-531, 2002.

[8] C.W Chiu and F.L Lin, Compact dual-band PIFA with multi-resonators, *Electronics Letters*, vol.38 no. 12., pp 538-540, June 2002.

[9] A. Mehdipour, A.-R. Sebak, C. W. Trueman, and T. A. Denidni, Compact multiband planar antenna for 2.4/3.5/5.2/5.8-GHz wireless applications, *IEEE Antennas and Wireless Propagation Letters*, vol. 11, 144–147, 2012.

[10] M. T. Islam, N. U. Anika, M. S. Mahmud, M. H. Islam, M. R. H. Abir and M. H. Chy, Design of a Microstrip Patch Antenna for both C-band and X-band Applications, *2020 2nd International Conference on Advanced Information and Communication Technology (ICAICT)*, pp. 7-10, 2020.

[11] A.Dahab, Mohamed and M. Ghouz, H. Hamed and Zaki, A.Z. Ahmed, High Gain Compact Microstrip Patch Antenna for X-Band Applications. *International Journal of Antennas* (JANT) vol.2, no.1, January 2016.

[12] HFSS, High Frequency Structure Simulator ver. 21, Finite Element Package. Ansys Corporation, Available: http://www.ansys.com.

[13] R. Mali, D. Lodhi and S. Singhal, Compact cpw fed nonagonal uwb antenna, 2021 *IEEE Indian Conference on Antennas and Propagation* (incap), Jaipur, Rajasthan, India, India, pp. 99-101, 2021.

[14] R. Mali, D. Lodhi and S. Singhal, Dual Band Circular Patch Antenna for RFID and Ultrawideband Applications, *2021 IEEE Indian Conference on Antennas and Propagation* (InCAP), Jaipur, Rajasthan, India, India, pp. 451-453, 2021.

DOI: http://dx.doi.org/10.32452/IJAMT.2023.301305

[15] R. Mali, F.L. Lohar, S. Singhal, Tri-band elliptical patch antenna for GPS and IRNSS applications. *Flexible Electronics for Electric Vehicles. Lecture Notes in Electrical Engineering*, Springer, Singapore, vol. 863, 2023.

[16] Alam, M.M., Azim, R., Sobahi, N.M. et al., A dual-band CPW-fed miniature planar antenna for S-, C-, WiMAX, WLAN, UWB, and X-band applications. *Science Reports*, 12, 7584, 2022.

[17] A.K. Saurabh, M.K Meshram, Compact sub-6 GHz 5G-multiple-input-multiple-output antenna system with enhanced isolation, *RF and microwave computer-aided Engineering*, vol-30, pp. 1-11, 2020.

[18] R. Mali, N.K. Sahu, K.K. Suman, R.K. Gangwar, Compact sub-6 GHz 5G-multiple-input-multiple-output antenna system with enhanced isolation, *International Journal of RF and Computer-Aided Engineering*, vol-32 ,no-11, pp.1-8, 2022.

Biography of the authors

Ravi Mali: He was awarded B.Tech (Hons.) degree from Govt Engineering College Jhalawar and M.Tech degree from Malaviya National Institute of Technology Jaipur Rajasthan, India in 2022. Currently, he is working as a Junior Research Fellow and pursuing (Ph.D.) in IIT(BHU), Varanasi UP in India. His research area of specialization is Reconfigurable Reflectarray Antenna, Multiple Input Multiple Output antenna, Dielectric Resonator Antenna, and wideband circular polarized antenna for GHz, mm-wave, and THz applications. He has published 4- Sci-articles, 5-Conferences, and 2-book chapters.

Rajkumar Jatav: He received his M.E. degree in electronics and telecommunication engineering from the Shri G. S. Institute of Technology and Science, Indore, India 2014. He is pursuing Ph.D. in electronics engineering at IIT (BHU), Varanasi, India. His research interests include SIW-based devices, leaky-wave antennas, and end-fire antennas.

Praveen Singh Rathore: He did his M.Tech degree in Electronics and Telecommunication Engineering from C.S.V.T.U. Bhilai, India, in 2014. He is currently working towards Ph.D. degree at Indian Institute of Technology (BHU), Varanasi, India. His current research interests include the reconfigurable antenna design for cognitive radio, MIMO antenna, and UWB antennas

Rupam Bharati: She did her Bachelors in Engineering and Masters in Engineering from BIT Mesra, Ranchi, Jharkhand, India in 2017 and 2019 respectively. Currently, she is pursuing her Ph.D. as a JRF (UGC NET) from IIT (BHU) in the Department of Electronics Engineering, Varanasi, UP, India. Her research area is Rectenna for wireless communication, reflectarray antenna, and metasurface based transmit-array antennas.

DOI: http://dx.doi.org/10.32452/IJAMT.2023.301305 © 2023 IJAMT