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ORIGINAL CONTRIBUTION

Design and Analysis of Microstrip Patch Antenna for Multiband Application with the Multiple Rectangular and a Plus Shaped Slots

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Abstract In the present study, the multiple rectangular and a plus shaped slots microstrip patch antenna (MPA) is designed and its performance has been analysed on the basis of various dielectric constants material such as silicon, silicon dioxide, polyethylene, Teflon, etc. Introduction of slots in MPA is important to find the optimized geometry. In this article, MPA has been designed with nine rectangular slots and one plus shaped slot for multiband application and investigate its accomplishment. The miniaturization has been achieved by inserting the rectangular and plus shaped slots that has been further created on FR4 substrate. The dimensions of this proposed MPA are 26 mm × 18.61 mm and the antenna is uniform from both the sides. The proposed antenna can operate on different frequencies with operating bands of 3.62 GHz for global system for mobile, 5.27 GHz for wireless fidelity (Wi-Fi), and 6.74 GHz for worldwide interoperability for microwave access (WiMAX). The proposed MPA might also be used for certain other broadband applications in the above respective frequencies. Computer simulation technology programme is utilized to characterize the parameters like Voltage Standing Wave Ratio, return loss (S_{11}), surface current, and radiation pattern.

Keywords Microstrip patch antenna · Return loss · VSWR · Surface current · Radiation pattern

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Introduction

The Microstrip patch antenna (MPA) has many benefits that make it popular in wireless communication, including its small weight, available with ease, simple physical geometry in two dimensions, low profile, simplicity in manufacture, dual polarisation and circular polarisation, mechanical endurance, and others. It has some important drawbacks which are narrow band, poor efficiency, spurious radiation, and gain issues. Slotted Microstrip antennas are used to address the aforementioned issues by enabling the same antenna to function at many bands and combining several standards of wireless communication into a single antenna system. Radiating patch which is in the form of slots in the ground plane may influence the surface current density and extending the total path length of current therefore antenna may be worked at multiband resonance. Cutting different slots into the construction of a microstrip antenna can produce multiband [1–7]. MPA with defected ground structure (DGS) structure can be used to enhance the performance. The design of microwave circuit with DGS might be used in different application to improve the accomplishment of the system. Designing a multiband antenna has grown in importance in the wireless industry during the past few years. Equipment that makes communication possible is an antenna. It minimises communication trafficking. Conversion of electrical energy into radio frequency energy is done by antenna therefore antenna may be termed as a transducer hence an antenna is termed as a fundamental component of any communication arrangement [8–12]. The second crucial consideration when designing any antenna is the multiband antenna. To put it simply, a multi—band antenna is one that can operate on many bands [13–16]. A multi—band antenna for numerous broadband applications is built in this study. It

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supports a variety of wireless bands including Worldwide Interoperability for Microwave Access (WiMAX) coverage from 3500 to 4500 MHz, Wireless local area network (WLAN) coverage from 5100 to 5800 MHz, and Long-Term Evolution (LTE) coverage from 7 to 10 GHz which is higher frequency levels. For multiband antennas, the ability to tune frequencies is critical. These antennas are generally complexly designed for several bands. However, four square slots can be quite helpful for creating many bands [17]. MPA is well matched device for wireless communications which can be easily combined with microwave circuits because of its low volume, thin profile, light weight and low cost might be worked at multiple frequencies for multiple applications [18]. In 5G applications, it may be more appropriate assortment. Its features are found as a high gain, enlarged bandwidth, enhanced efficiency and reduced power [19]. The copper or gold patch of thin metallic, dielectric substrate and ground plane is needed in such device. The dielectric substrate is properly separated as of the ground plane and patch in this design. The various patch shapes for antenna design like dipole, triangular, elliptical, square, rectangular and circular are considered as per required application [20]. The particular requirement, reconfigured frequency and multiband antennas are mainly considered at the time of its designing. In 5G wideband applications realized by microstrip antennas using various techniques such as DGS and metamaterials are also conventional methods [21–26]. A bandwidth improvement methods for microstrip patch antenna (MPA) as impression of thick and lesser permittivity and multilayer substrate, parasitic essentials, slots along with notches, shorting pin and wall, defected ground architecture, metamaterial constructed split-ring resonator structure with fractal geometry, and finally composite right/left-hand transmission line approach have been used while in particle swarm optimization (PSO) optimized antenna might be attained by comparing its performance with both initial conventional 'T' shaped-slot encumbered antenna which may be manually optimized antenna [27, 28].

Hence in the present study the rectangular and plus shaped might be new with existing techniques. In the present study a new design and simulation of MPA has been optimized with the help of several existing design using some standard basic equations. The several expressions taken in the study are the basic standard equations to develop the patch antenna. Firstly, it has been slitted the slots in patch for achieving the multiband. According to the existing theory "the patch the impedance should be 377 ohms on the edges" and the multiband values have also been taken through standard references. If the slots have been cut on the patches to improve the impedance matching and also to achieve the multiband.

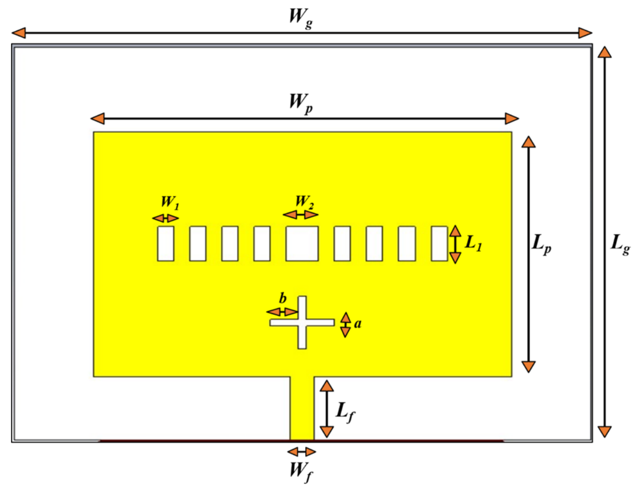

Fig. 1 The geometric structure of designed slotted-patch antenna

Table 1 Dimensions of proposed design of slotted patch antenna

Parameters	Parameters detail	Dimensions (mm)
W_g	Width of the antenna	35.92
L_g	length of the antenna	29.81
W_p	Patch's width	26
L_p	Patch's length	18.61
W_f	Width of feed line	1.50
L_f	Length of feed line	4.80
W_1	Width of the eight rectangular form slots	1
W_2	A centre rectangular slot width	2
L_1	Length of the eight rectangular form slots	2.60
a	Plus-shaped slot arm length	1.75
b	Plus-shaped slot arm width	0.50

Design of Microstrip Patch Antenna for Multiband Application

Multiband antennas with different frequencies are used for wireless applications to simulate the number of bands. For multiband operation, the proposed MPA figure depicts nine rectangular slots, a plus shape slot, and a Microstrip line. Each slot is symmetrically carved in length and width. Antenna dimensions are also picked in the correct sequence. The suitable outcomes of the proposed antenna are obtained by adjusting the size and length or width because this is a radiating patch; slots are carved from the centre. The geometrical structure of the microstrip antenna is illustrated in Fig. 1 while the dimensions of the antenna for designing have been shown in Table 1.

For multiband operation, the modelling of multiple rectangular and plus shape slots are used to design multiband

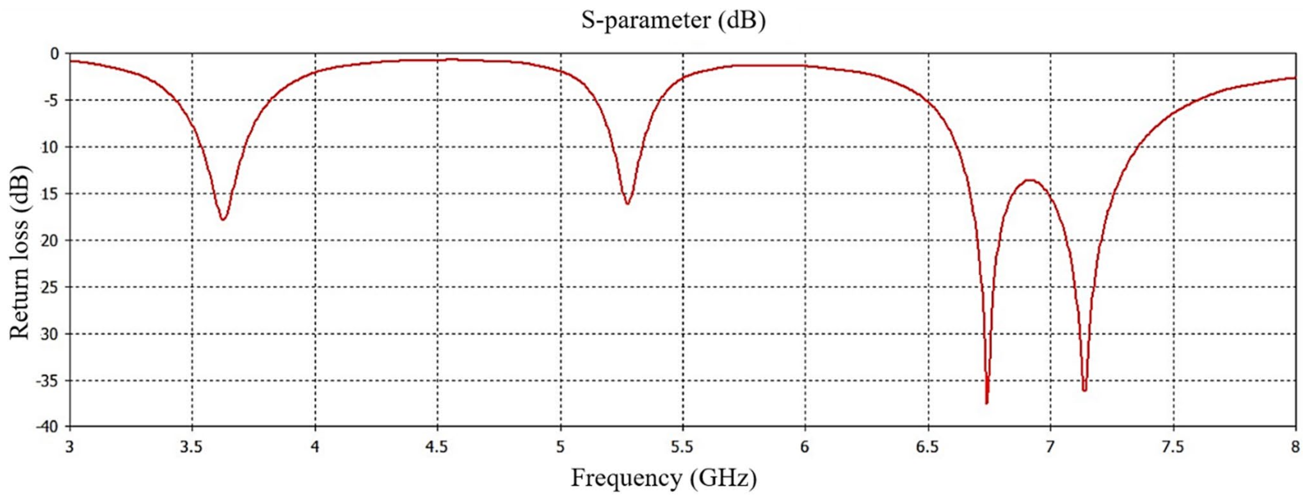

Fig. 2 Multiband antenna return loss Vs frequency

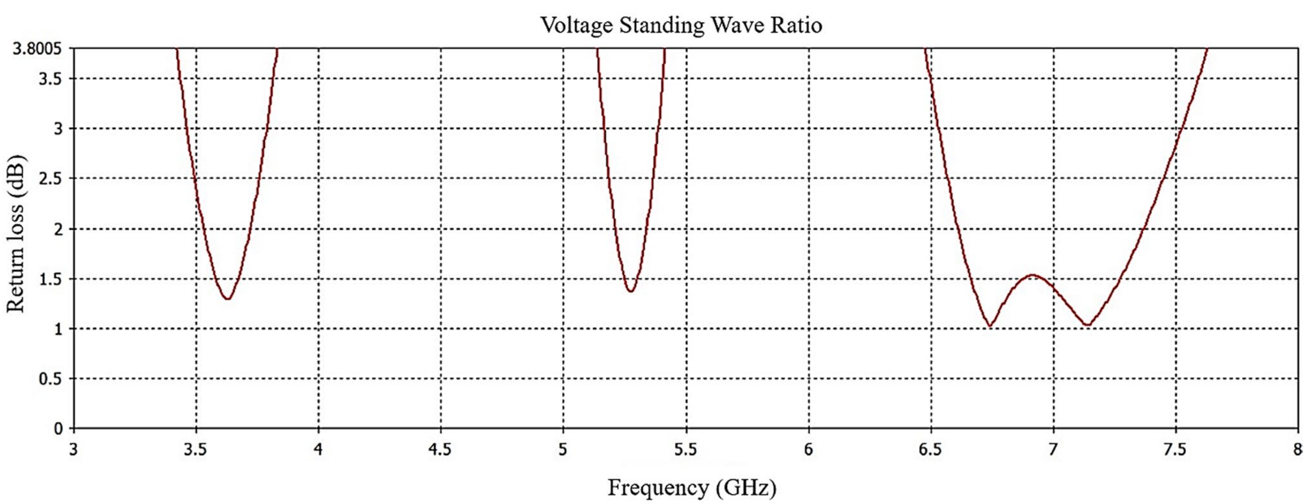

Fig. 3 VSWR vs frequency

microstrip patch. Firstly, a simple rectangular antenna designed in the present study, and etched the slots in the rectangular and plus-shaped structure because the patch antenna in the middle having 0 Ω impedance. After etching the slots, the direction of the current in the antenna has been changed which results the antenna resonated at three different frequencies. Nine rectangular slots and a plus-shaped slots have been etched in the antenna for achieving the miniaturization. It is also observed that these etched slots are the main cause of resonating antenna at three different frequencies. Before adding the slots, the antenna resonated at only one frequency 3.6 GHz but after etching the slots it is resonating at multiple bands.

The proposed design was built by using FR-4 substrate. The dielectric constant is 4.4 while loss tangent is 0.0024

Table 2 Comparison of different Antennas for different slots in Patch

Antenna type	Resonant frequency (in GHz)	Return loss (in dB)	VSWR
Simple MPA	9.8	–32.07	1.1
MPA with R1, R2 slot	9.7	–23.78	1.17
	12.05	–10.61	1.9
MPA without DGS	9.47	–26.83	1.03
	11.7	–27.63	1.07
Proposed design MPA	3.63 GHz	–17.816	1.29
	5.27 GHz	–16.096	1.37
	6.74 GHz	–37.593	1.02

Table 3 The comparison of simulated MPA results with the measured proposed antenna with DGS

Antenna	Resonant frequency (in GHz)	Return loss (in dB)	VSWR
Simulated MPA	3.63 GHz	–17.816	1.29
	5.27 GHz	–16.096	1.37
	6.74 GHz	–37.593	1.02
Measured MPA	3.69 GHz	–15.06	1.31
	5.369 GHz	–18.0	1.39
	6.84 GHz	–25.0	1.04

of the chosen FR-4 substrates. The overall dimensions of the antenna are 35.92 × 29.81 mm length (Lg) and width (Wg) in relation to the centre frequency and thickness is 1.6 mm. The patch's length and width are (L_p x W_p) 18.61 mm × 26 mm in copper material. The width and length of the eight rectangular form slots cut symmetrically are ($W_1 \times L_1$) 1 mm × 2.60 mm, with a centre rectangular slot length and width of ($W_2 \times L_2$) 2 mm × 2.60 mm. To maximize radiation, each slot has been sliced from the patch's centre. A conventional microstrip line feed is implemented in the proposed design. This microstrip feed line having dimensions W_f and L_f, 1.50 mm × 4.80 mm [22]. To compute the substrate's length and width of the proposed MPA in terms of wavelength (λ). The patch's width of the proposed antenna can be calculated by using the standard expression is as shown in Eq. (1).

$$W_p = \frac{c}{2f_r\sqrt{\frac{\varepsilon_r+1}{2}}} \tag{1}$$

where the value of ε_r is 4.4, the value of c is 3×10^8 *m/sec* and f_r is 3.6 *GHz*.

The effective dielectric constant (ε_{reff}) in terms of W_p can be calculated using the expression is as shown in Eq. (2).

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12h}{W_p}\right)^{-\frac{1}{2}} \tag{2}$$

The patch's effective length, ΔL due to fringing effect can be calculated using the expression is as shown in Eq. (3).

$$\Delta L = 0.412h\frac{\left(\varepsilon_{reff} + 0.30\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \tag{3}$$

The effective length of the patch antenna (L_{eff}) can be calculated by using expression is as shown in Eq. (4).

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \tag{4}$$

The actual length of the patch antenna (L_p) can be calculated by using the expression is as shown in Eq. (5).

$$L_p = L_{eff} - 2\Delta L \tag{5}$$

In order to establish the ground plane's length (L_g) and width (W_p), the expressions are as shown in Eq. (6) and Eq. (7).

$$L_g = 6\text{h} + L \tag{6}$$

$$W_p = 6h + W \tag{7}$$

Results and Discussion

The CST software has been used for simulation of the proposed MPA and the hardware of the antenna is also fabricated in the lab. The simulated and real antenna results are shown here. The result has been calculated with important parameters which are shown in the figure and discussed. Section 3.1 shows the return loss, Sect. 3.2 shows the VSWR, Sect. 3.3 shows the surface current distribution, Sect. 3.4

Table 4 The simulation result of proposed microstrip patch antenna

Dielectric name	Value of dielectric constant	Resonant frequency in GHz (lowest)	S11 (dB)	VSWR
Teflon	2.1	5.085	–23.74	1.139
Rogers RT/D uroid 5880	2.2	5.075	–19.73	1.230
Polyethylene	2.25	4.99	–14.88	1.440
Neltec NH9294	2.94	8.6	–13.446	1.540
Silicon Dioxide	4	4.895	–26.75	1.096
FR4_Epoxy	4.4	4.515	–15.53	1.402
Mica	5.7	7.65	–24.05	1.134
FR4	4.4	3.63 GHz	–17.816	1.29

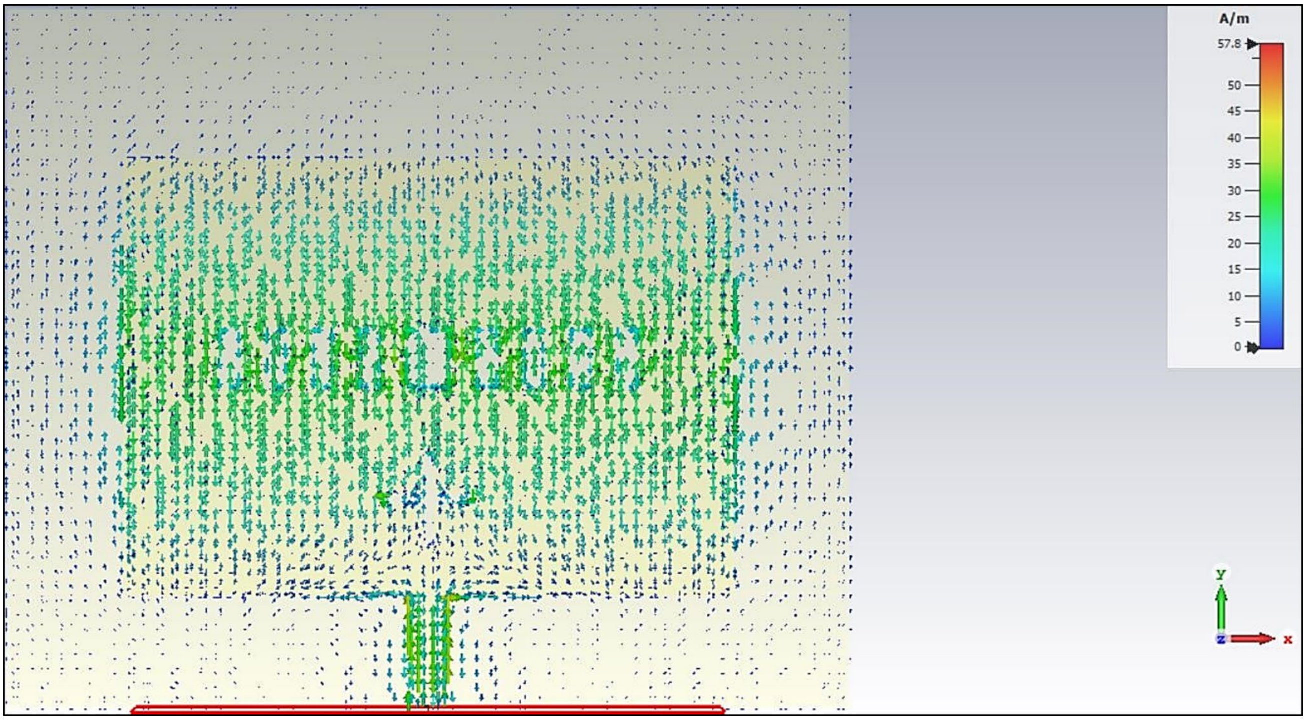

Fig. 4 Distribution of current at 3.625 GHz

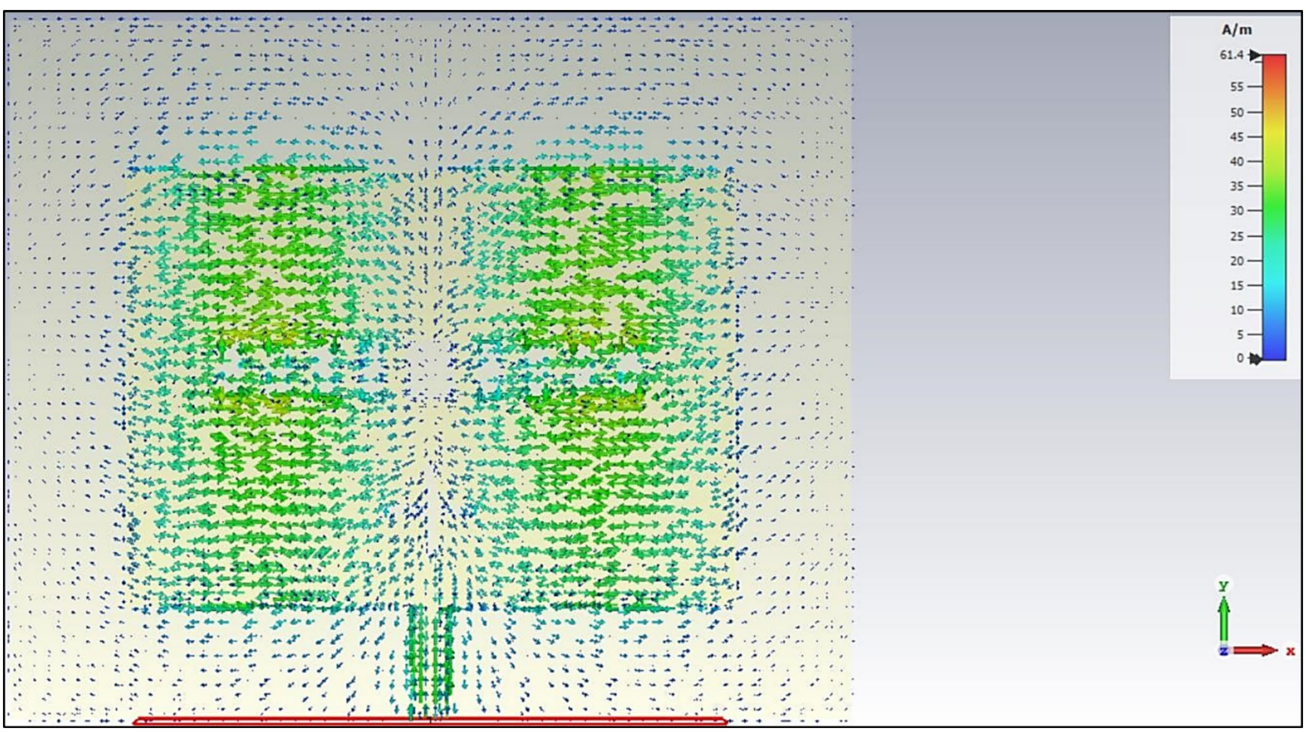

Fig. 5 Distribution of current at 5.2749 GHz

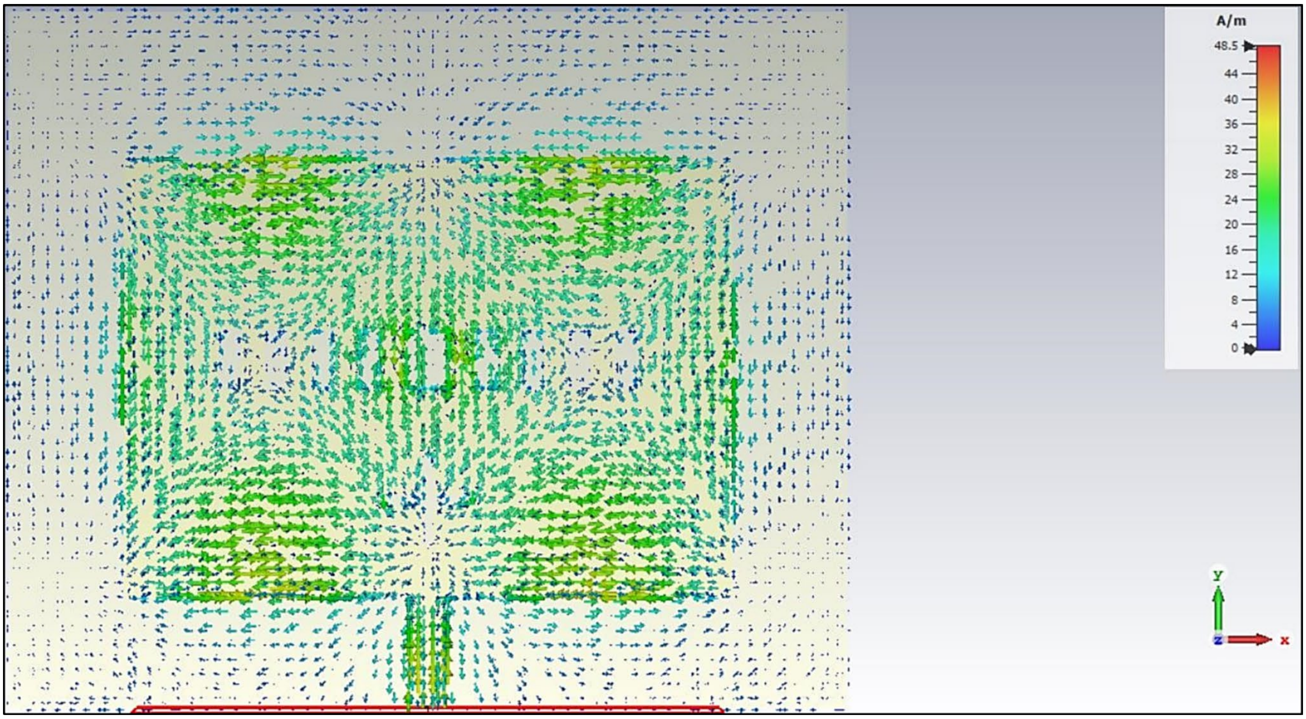

Fig. 6 Distribution of current at 6.74 GHz

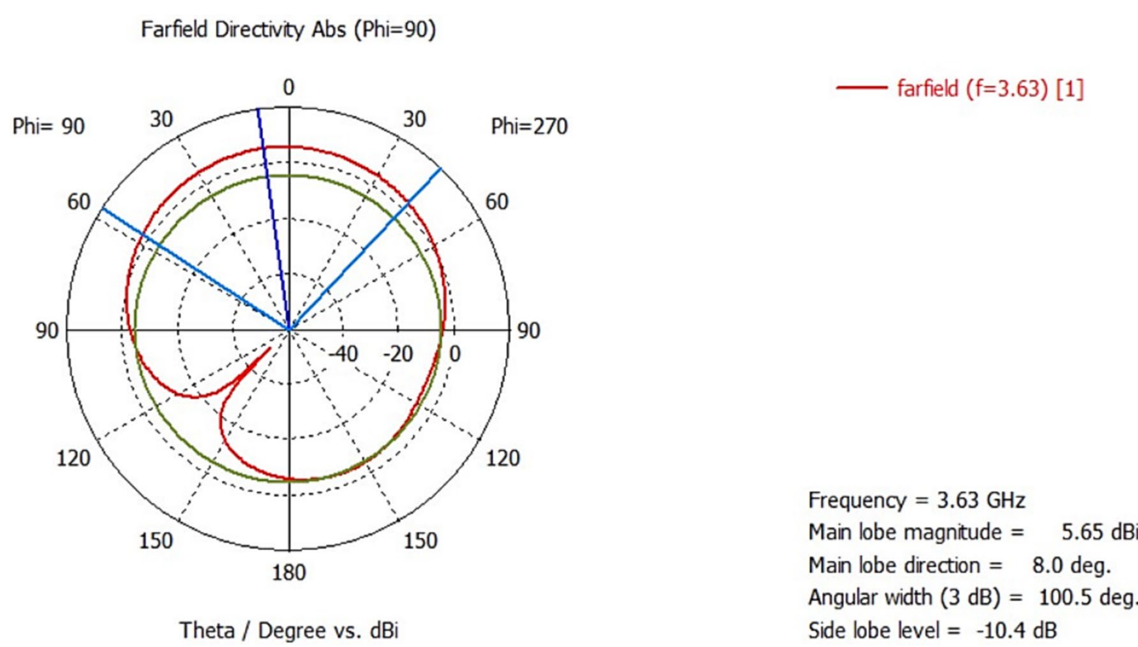

Fig. 7 Radiation pattern at 3.63 GHz frequency (two dimensional)

shows the radiation pattern and Sect. 3.5 shows the compare of measured versus simulation results.

S_{11} or Return Loss

Figure 2 shows that the least number of losses is present there, according to multiband antenna return loss modelling [23]. Three sites were found in this investigation where

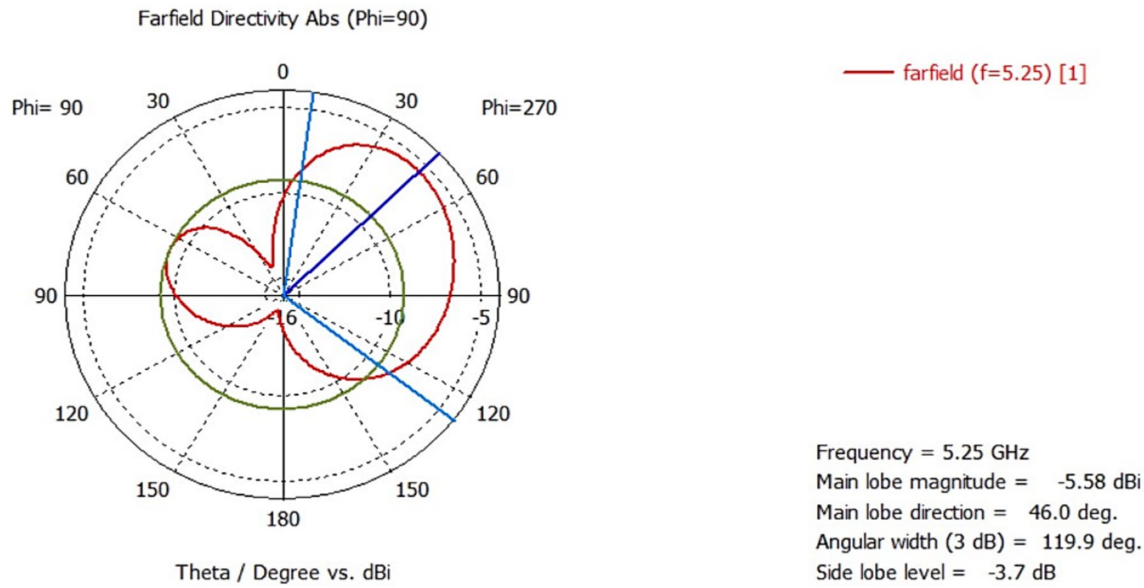

Fig. 8 Radiation pattern at 5.25 GHz frequency (two-dimensional)

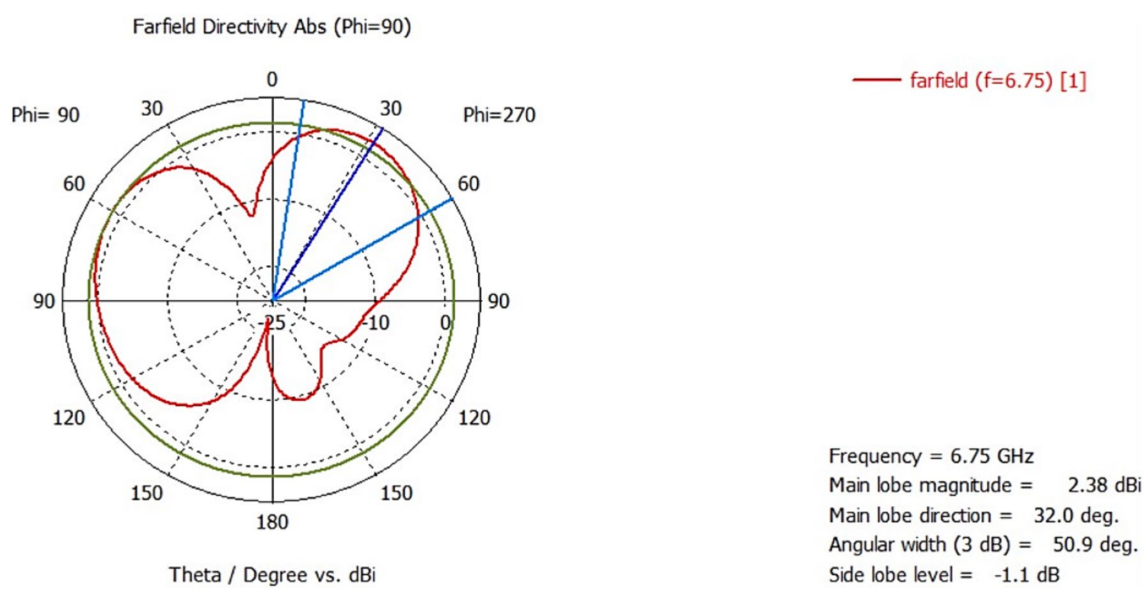

Fig. 9 Radiation pattern at 6.75 GHz frequency (two-dimensional)

lowest losses were attained for their respective frequencies; these are -17.816 at 3.63 GHz, -16.096 at 5.27 GHz, and -37.593 at 6.74 GHz. These return loss value shows that the antenna can produce the desired result. Multiband antenna Return loss Vs frequency.

VSWR Calculation

VSWR vs frequency result of MPA is displayed in Fig. 3. VSWR of the proposed design antenna has been observed below or equal to 2. VSWR patterns are 1.29, 1.37, and 1.02 at frequencies of 3.63, 5.27, and 6.74 GHz, respectively. These value shows that it has less noise.

The projected MPA has been simulated by CST MWS, the electromagnetic simulation software. The return loss, gain,

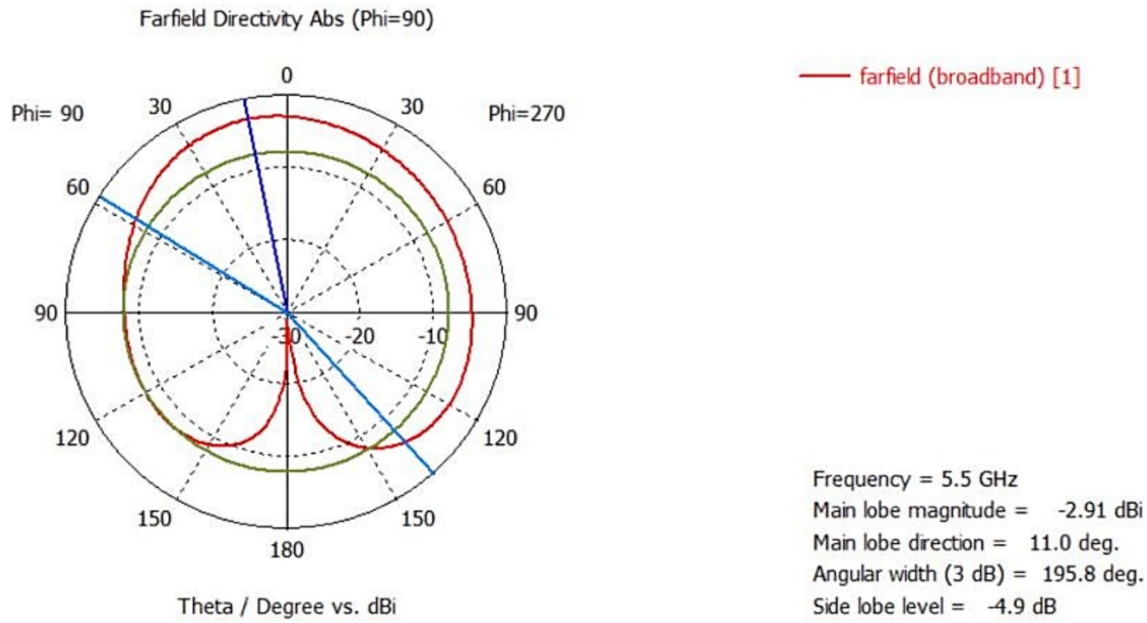

Fig. 10 Radiation pattern for broadband (two-dimensional)

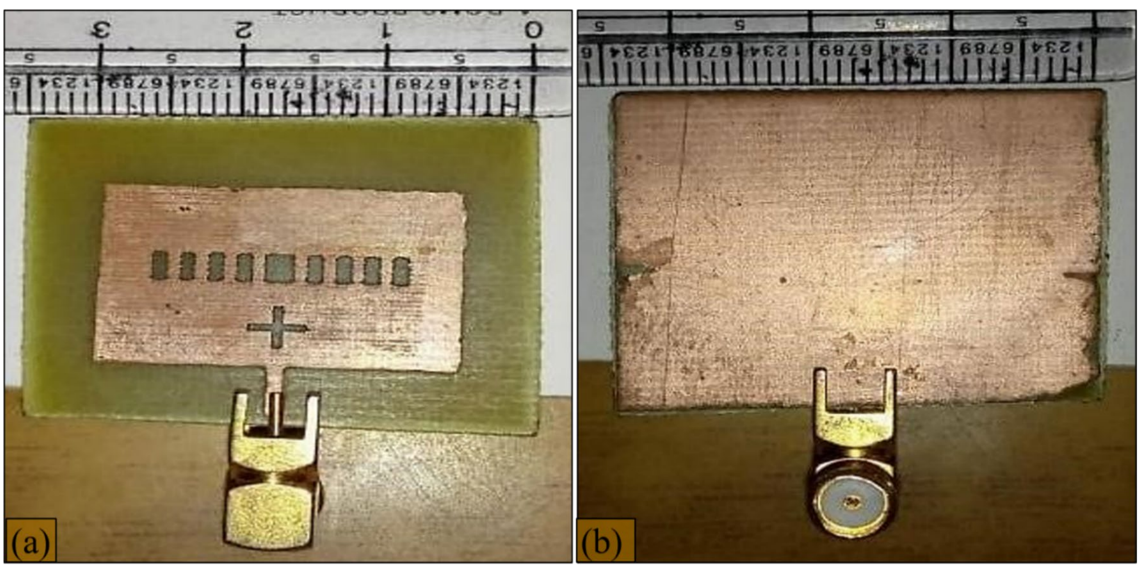

Fig. 11 Constructed prototype view of proposed antenna **a** Top view and **b** Bottom view

VSWR, and directivity have been investigated as shown in Figure 3. The simulated result of MPA operates at resonant frequency by presenting different types of rectangular slots. The simple patch has been operating at a single frequency of 3.6 GHz while introducing the slots two bands have also been attained and their return losses have been improved significantly. VSWR is a main parameter of MPA and it should be less than or equal to 2. This prerequisite might be satisfied by all the resonant frequencies. The difference in bands, resonant frequency, return losses and the VSWR of MPA by different slots is presented in Table 2. Hence, it can be realized that by using DGS both the return loss and the bandwidth has been improved significantly. The assessment of simulated results of proposed MPA with DGS structure is presented in Table 3. Hence, from Table 3 it can be compared that the simulated and measured results are very much inline which reflect that the proposed MPA might also be

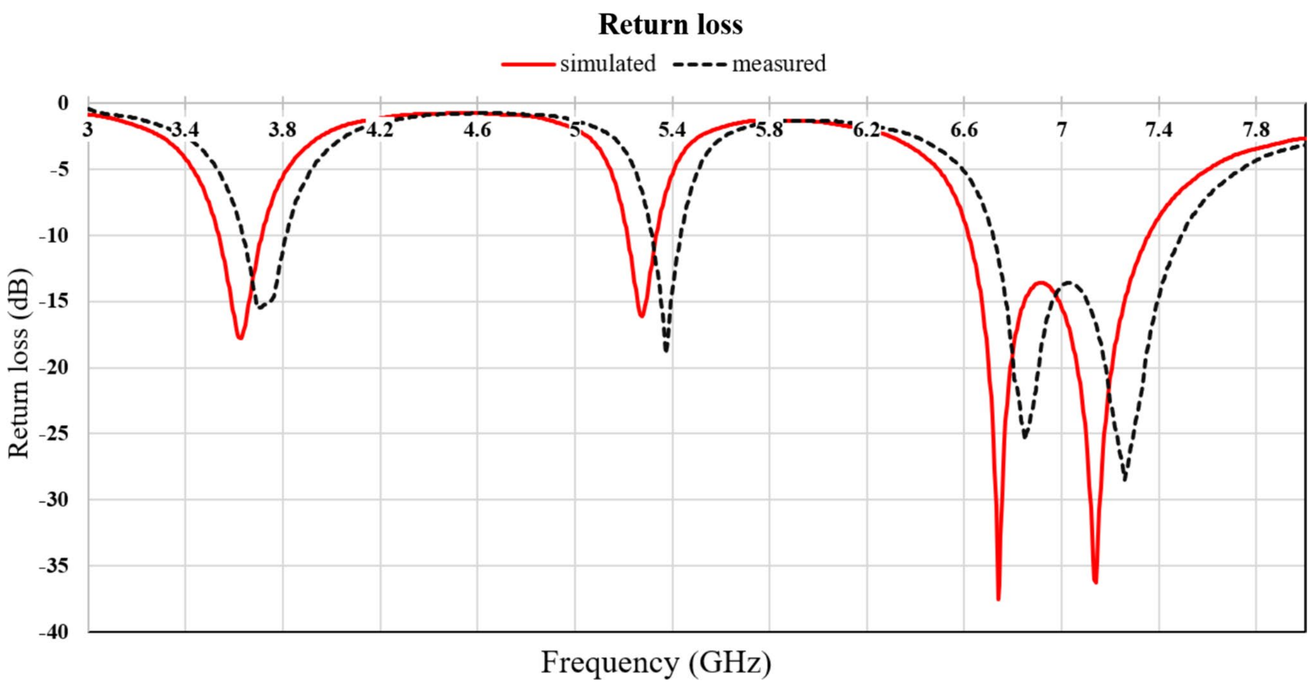

Fig. 12 Measured vs simulated graph of return loss

used practically. Finally, the VSWR of proposed antenna came out 1.02, which is significantly good.

It has been observed that resonant frequency is varying with the dielectric constant of material. When dielectric constant of the substrate FR4_Epoxy is 4.415, resonant frequency is lowest at 4.515 GHz. Although some dielectric constant is nearly similar to Mica ($\varepsilon_r = 5.7$) has shown the lowermost resonant frequency as 7.65 GHz as tabulated in Table 4. It is also noticed that the return loss (−10dB) has varied with the change of dielectric constant. Hence, it is reflected that the improved return loss can be provided by the material like Teflon, silicon Dioxide, and silicon.

Surface Current Distribution

A patch antenna's current distribution characteristics might also be observed in surface current distribution [24–26]. The surface current distribution for the following frequencies is shown in Figs. 4, 5, and 6 which is at 3.625, 5.2749, and 6.74 GHz. These value shows that antenna is radiating good energy flow. Here, the multiple slots are the main reason for multi-spurious radiation because after etching the slots the current has been distributed in multiple directions. Therefore, the current passes in multiple directions of the antenna which is important and helpful in multi-spurious radiations.

Radiation Pattern Calculation

An antenna's radiation pattern reveals its main, minor, side, and rear beam width [25]. The direction of greatest radiation is represented by the main lobe. 3.63, 5.27, and 6.74 GHz are three different operating frequencies that are displayed in these three different radiation patterns as shown in Figs. 7, 8 and 9. Two-dimensional radiation pattern for Broadband is shown in Fig. 10.

Measured Verses Simulated Results

The fabricated prototype's front view and bottom view of the proposed antennas are depicted in Fig. 11. The designed rectangular slots along with plus shaped slot are clearly visible in Fig. 11a and without slotted is shown in Fig. 11b. The comparison between measured and simulated results in the form of graph is shown in Fig. 12. The graph represented the return loss of real antenna and simulated antenna with respect to frequency (GHz) as shown in Fig. 12. This graph also depicted that physical antenna is radiating relatively good and very much in line with the simulated result. There is small difference between measured and simulated might be due to fabrication tolerance and connector losses etc.

Conclusion

The present study covers all the major findings, including the good VSWR pattern, radiation pattern and better surface current. The entire output of the present multi-band antenna showed the better performance. First optimization of material, conclude that improved return loss has been achieved by using FR4 substrate at frequency 4.515 GHz. The VSWR of proposed antenna came out 1.04 for measured and 1.02 for simulated which is significantly better. The proposed antenna has radiated good energy flow at different operating frequencies of 3.63, 5.27, and 6.74 GHz. The direction of highest radiation has also been represented by the main lobe at same frequencies. The comparison of measured and simulated results were ned and these results clearly showed that the antenna may be used in multiband. These frequencies can all be used for Bluetooth, Wi-Fi, WLAN, WiMAX and other broadband applications and are all multiband suitable. The miniaturization has been achieved by inserting the rectangular and plus shaped slots. There is good agreement between the physical antenna results and simulated antenna results. The antenna is compacted and devours significantly less power, acceptable return loss, considerable gain makes the antenna for possible applications. The forthcoming work might embrace the fabrication of antenna and authenticating the attained results in the actual world. The low gain, low efficiency, slight bandwidth and significant low power of the proposed antenna may have the possible practical applications.

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Declarations

Conflict of interest The author does not have any conflict of interests.

References

1. R.K. Verma, R.L. Yadava, D. Balodi, An inset-feed on-chip frequency reconfigurable patch antenna design with high tuning efficiency and compatible radome structure for broadband wireless applications. Int. J. Sci. Technol., Scientia Iranica, pp. 1–24 (2021)
2. S.K. Vijay, J. Ali, P. Yupapin, et al, A triband EBG loaded microstrip fractal antenna for THz application. Int. J. Sci. Technol., Scientia Iranica, pp. 1–11 (2021)
3. M, Kapahi, E. Gupta, et al, Design of circularly polarized irregular octagonal shaped and dumbbell slotted planar and conformal patch antenna. Int. J. Sci. Technol., Scientia Iranica, pp. 1–12 (2021)
4. K. Manohar, V. Bolisetti, S. Kumar, An investigation of different methodology used for achieving compact multiband microstrip antenna for wireless application. Next Generation Information Processing System, Singapore, Springer, pp. 151–160 (2021)
5. A. Singh, K. Shet, D. Prasad, A.K. Pandey, M. Aneesh, A review: circuit theory of microstrip antennas for dual-, multi-, and ultra-wideband. Modul. Electronics Telecommun., pp 105–123 (2020)
6. J.F. Qian, F.C. Chen, K.R. Xiang, Q.X. Chu, Resonator-loaded multi-band microstrip slot antennas with bidirectional radiation patterns. IEEE Trans. Antennas Propag.Propag. **67**(10), 6661–6666 (2019)
7. S.Y. Fatah, E.K. Hamad et al., Design and implementation of UWB slot-loaded printed antenna for microwave and millimeter wave applications. IEEE Access **9**, 29555–29564 (2021)
8. R. Kumar, M.V. Kartikeyan, Design and simulation of multi band compact microstrip patch antenna. In: Indian Conference on Antennas and Propagation (InCAP), IEEE, pp. 1–4 (2019)
9. R. Arya, D.K. Raghuvanshi, Design of asymmetrical multiple open slot loaded microstrip antenna for WiBro/WiMAX/WLAN band application. Mod. Phys. Lett. B **34**(18), 2050198 (2020)
10. N. Agrawal, J.A. Ansari, N. Nitin, M. Siddiqui, S.S. Sayeed, Design and Analysis of W-Slot Microstrip Antenna. In: Recent Trends in Communication, Computing, and Electronics. Springer, Singapore, pp. 85–94 (2019)
11. T. Ali, R.C. Biradar, A compact hexagonal slot dual band frequency reconfigurable antenna for WLAN applications. Microw. Opt. Technol. Lett.. Opt. Technol. Lett. **59**(4), 958–964 (2017)
12. T. Ali, R.C. Biradar, A miniaturized Volkswagen logo UWB antenna with slotted ground structure and metamaterial for GPS, WiMAX and WLAN applications. Prog. Electromagnet. Res. C **72**, 29–41 (2017)
13. Y. Cao, B. Yuan, G.F. Wang, A compact multiband open-ended slot antenna for mobile handsets. IEEE Antennas Wireless Propag. Lett. **10**, 911–914 (2011)
14. M.J. Chiang, S. Wang, C.C. Hsu, Compact multifrequency slot antenna design incorporating embedded arc-strip. IEEE Antennas Wirel. Propag. Lett.Wirel. Propag. Lett. **11**, 834–837 (2012)
15. L. Dang, Z.Y. Lei, Y.J. Xie, G.L. Ning, J. Fan, A compact microstrip slot triple-band antenna for WLAN/WiMAX applications. IEEE Antennas Wirel. Propag. Lett.Wirel. Propag. Lett. **9**, 11781181 (2010)
16. Z. Du, K. Gong, J.S. Fu, B. Gao, Analysis of microstrip fractal patch antenna for multiband communication. Electron. Lett. **37**(13), 1 (2001)
17. L. Luo, Z. Cui, J.P. Xiong, X.M. Zhang, Y.C. Jiao, Compact printed ultra-wideband monopole antenna with dual band-notch characteristic. Electron. Lett. **44**(19), 1106–1107 (2008)
18. L. Prasad, B. Ramesh, K.S. Kumar, K.P. Vinay, Design and implementation of multiband microstrip patch antenna for wireless applications. Adv. Electromagnet. **7**(3), 104–107 (2018Aug 19)
19. MS Rana, BK Sen, M Tanjil-Al Mamun, MS Mahmud, MM Rahman, A 2.45 GHz microstrip patch antenna design, simulation, and analysis for wireless applications. Bull. Electrical Eng. Informat. **12**(4), 2173–2184 (2023)
20. MS Rana, SI Islam, S Al Mamun, LK Mondal, MT Ahmed, MM Rahman, An S-band microstrip patch antenna design and simulation for wireless communication systems. Indonesian J. Electrical Eng. Informat. IJEEI **10**(4), 945–954 (2022)

21. H. El-Hakim, H.A. Mohamed, synthesis of a multiband microstrip patch antenna for 5G wireless communications. J. Infrared MillimeterTerahertz Waves **21**, 1–7 (2023Aug)
22. A.F. Sheta, M.A. Alkanhal, Compact dual-band tuneable microstrip antenna for GSM/DCS-1800 applications. IET Microwaves Antennas Propag.Propag. **2**(3), 274–280 (2008)
23. O. Quevedo-Teruel, E. Pucci, E. Rajo-Iglesias, Compact loaded PIFA for multi frequency applications. IEEE Trans. Antennas Propag.Propag. **58**(3), 656–664 (2009)
24. M. Nikolic, A. Djordjevic, A. Nehorai, Microstrip antennas with suppressed radiation in horizontal directions and reduced coupling. IEEE Trns. Antennas Propag **53**(11), 34693476 (2005)
25. K. Buell, H. Mosallaei, K. Sarabandi, Metamaterial insulator enabled super directive array. IEEE Trans. Antennas Propag.Propag. **55**(4), 1074–1085 (2007)
26. Ghosh S, Ghosh A, Sarkar I. Design of probe feed patch antenna with different dielectric constants. In: 2017 Devices for Integrated Circuit (DevIC) 2017 Mar 23 (pp. 813–816). IEEE
27. B. Mishra, R.K. Verma, N. Yashwanth, R.K. Singh, A review on microstrip patch antenna parameters of different geometry and bandwidth enhancement techniques. Int. J. Microw. Wirel. Technol.Microw. Wirel. Technol. **14**(5), 652–673 (2022Jun)
28. R.K. Verma, D.K. Srivastava, Design, optimization and comparative analysis of T-shape slot loaded microstrip patch antenna using PSO. Photon Netw. Commun.Netw. Commun. **38**, 343–355 (2019Dec)