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RESEARCH ARTICLE

DESIGN AND ANALYSIS OF MULTI-BAND COMPACT MICROSTRIP ANTENNA IN GSM1900/WLAN/WiMAX/DSRC/X-BAND FREQUENCY BANDS FOR VEHICLE APPLICATIONS

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ABSTRACT

This study focuses the design and analysis of a compact, multi-band microstrip patch antenna for wireless communications operations. The design antenna exhibits distinct quad resonance frequency bands I from 1.879 GHz to 1.986 GHz, II from 3.1 GHz to 3.87 GHz, and III from 4.97 GHz to 6.515 GHz, IV from 7.26 GHz to 8.6 GHz, which covers GSM 1.900 GHz, WLAN (5.2/5.8 GHz), DSRC 5.9 GHz and WiMAX (3.5/5.5 GHz) bands. In addition, it can also support the X-band from 7.26 to 8.6 GHz. The antenna is designed on an inexpensive substrate of FR4 with dimensions of 36(L) × 25(W) mm2 and consists of two branches of curved strips for a quad-band response. The antenna is designed and analyzed using electromagnetic 3D computer simulation software. The designed antenna can provide advantages in GSM/WLAN/WiMAX/DSRC/X-band satellite applications for vehicle communication with four resonant frequency bands, nearly omnidirectional radiation characteristics, and acceptable gain.

Keywords: *Microstrip antenna, multi-band antenna, WLAN, WiMAX, DSRC Band, Vehicle communication*

1. INTRODUCTION

Recently, wireless communication technology has shown tremendous improvement. This technology, which brings great convenience to people's activities, has ensured that it is adopted in almost every aspect of human life. With this technology, we can connect almost any device today without cables. On the other hand, developments in computing, cloud computing, and the internet of things (IoT) are paving the way for automation and intelligence in everyday work. Because of this progress, interest in intelligent transportation systems (ITS) and vehicle communication is increasing. Wireless communication, sensing capabilities, and advanced computing play a vital role in ITS [1–4].

Modern automobile (vehicle) technology has become a sector that has recently shown increasing interest in various wireless communication systems to improve both traffic flow and traffic safety [5]. With wireless vehicle communications in the ITS, many new functions, such as traffic alerts, road emergency alerts, and safety alerts, can be easily realized. Thus, drivers and other users can share real-time information to prevent potential traffic hazards and increase traffic efficiency [6].

The antenna plays a crucial role at the front end of wireless systems and is an important component of in-vehicle communication systems. In recent years, Monopole, Microstrip Patch, On-Glass, Bonded Foil, and Fractal Antennas have been among the commonly used antenna technologies for in-vehicle communication. However, the microstrip patch antenna is more popular than other in-vehicle communication technology. It is widely used due to its unobtrusive low profile, lightweight, flat structure, and ease of integration into components such as the vehicle bumper, fender, roof, or the back of the trunk lid [3, 7].

An ITS uses GPS, WLAN, WiMAX, Dedicated short-range communication (DSRC), etc., to transmit traffic information over short distances. It should cover different wireless communication standards, such as Multi-band antennas that have the potential to connect numerous professional forms in a single device [8]. In this case, it is most suitable if the antenna is multi-band operable [9]. Multi-band, low-profile, low-cost antennas that combine multiple antennas in a system are of great interest in the ITS. To create multi-band resonance, techniques such as creating slots in the antenna patch and ground plane, adding fractals of various shapes, and parasitic loading are commonly used [8,10,11]. In the literature, dual-band [1,12,13] and multi-band [14–16] antennas operating in WLAN, WiMAX, DSRC, and other communication bands have been studied for vehicle communication. DSRC is a standard wireless technology and operates in the 5.9 GHz (5.850 - 5.925 GHz) frequency band to enable vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) cooperation in ITS. [17,18].

In this study, a quad-band low-profile microstrip patch antenna with a simple geometric architecture is proposed for vehicle communication applications. The antenna covers the GSM 1.900 GHz, WiMAX3.5/5.5 GHz, WLAN 5.2/5.8 GHz, DSRC 5.9 GHZ and X-band satellite frequency bands. WLAN applies to high-speed low-energy internet access in the vehicle, and with DSRC vehicle communication, it can provide the driver with some advantages, such as accident prevention on the roads. This article is organized into four sections. Detailed geometric structure and antenna design are presented in section 2. The simulated reflection coefficient and radiation pattern results are discussed and presented in section 3, and concluding explanations of this article are given in section 4.

2. ANTENNA DESIGN

This study aims to propose a microstrip antenna operating in multiple frequency bands for vehicle communication applications. In addition, the antenna must have an omnidirectional radiation pattern and good impedance matching that supports vehicle-to-vehicle and vehicle-to-roadside communications. Figure 1 shows the geometry and parametric configuration dimensions of the proposed quad-band antenna for GSM, WiMAX, WLAN, DSRC, and X-band bands operation. The antenna is designed on an inexpensive FR4 substrate with a thickness of 1.57 mm, a relative permittivity of 4.4, a loss tangent of 0.02, and a compact size of 36×25 mm2. The conductor layers are

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realized using a thick copper material of 0.017 mm (Tcop=1 Oz). As shown in Figure 1a, the top side of the FR4 substrate consists of the two branches of curved strip radiating element and a 50 Ω microstrip inset feed line for good impedance matching at the selected bands. The width of feed line is set at 3.08 mm. As shown in Figure 1b, a rectangular partial ground plane is printed on the bottom layer of the substrate for omnidirectional radiation. In addition, a small slot (WgsxLgs) was created in the ground plane for good impedance matching. The antenna structure was designed and analyzed using 3D commercial electromagnetic simulation software (CST). Table 1 summarizes the detailed dimensions of the proposed design. The final all design parameters of the antenna structure are showed in Table 1 (units are in mm).

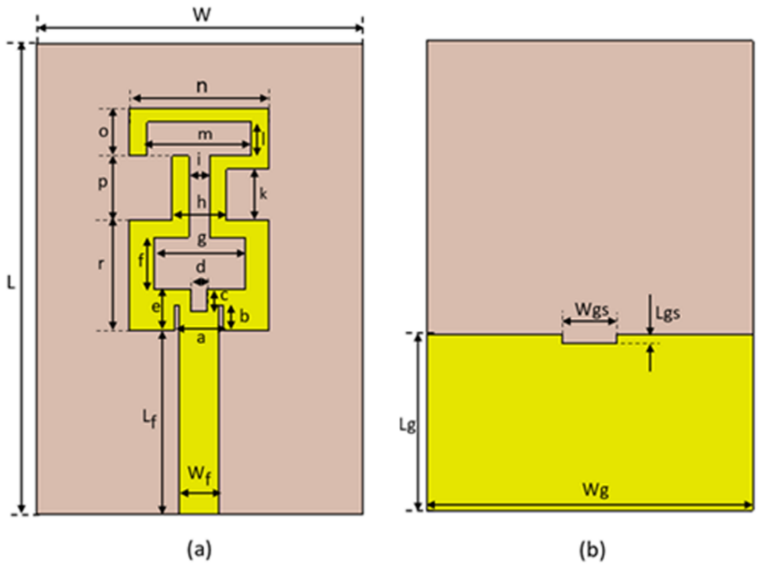

Figure 1. Proposed multi-band antenna. (a) Top architecture (b) Bottom architecture.

Table 1. The design parameters of the proposed antenna (mm).

W	L	W_f	L_f	a	b	c	d
25	36	3.08	14	3.68	2	1.7	1.2
e	f	g	h	i	k	l	m
3.2	4	7	4.2	1.6	3.9	2.6	8
n	o	p	r	W_g	L_g	W_{gs}	L_{gs}
10.7	3.7	4.9	8.5	25	13.5	4.2	0.65

3. SIMULATION RESULTS AND ANALYSIS

The reflection coefficient (S_{11}), radiation patterns, gain and radiation efficiency performance parameters of the antenna were simulated and analyzed. Figure 2 shows the frequency versus reflection coefficient (S-parameter) curve calculated via simulation. Based on $S_{11} \leq -10$ dB criteria, the calculated S_{11} shows that Antenna realizes four resonances at 1.936 GHz, 3.425 GHz, 5.89 GHz, and 7.8 GHz, with the corresponding frequency bands of 1.879–1.986 GHz, 3.10–3.87 GHz, 4.97–6.515 GHz, and 7.26–8.6 GHz. Results S11 indicate that the first resonance frequency at 1.936 GHz operates in the GSM 1.900 GHz (1.850-1.990 GHz) band, and its bandwidth is near the GSM band (For $S_{11} \leq -6$ dB criteria, it covers GSM 1.900 GHz band). The second resonance frequency at 3.43 GHz covers the WiMAX 3.5 GHz (3.30-3.80 GHz) band. The third resonance frequency at 5.9 GHz cover the WLAN 5.2 GHz/5.8 GHz (5.15-5.35, and 5.725-5.85 GHz), WiMAX 5.5 GHz (5.25-5.85 GHz), DSRC 5.9 GHz (5.850-5.925 GHz) bands. The fourth resonance frequency at 7.8 GHz operates in the X-band.

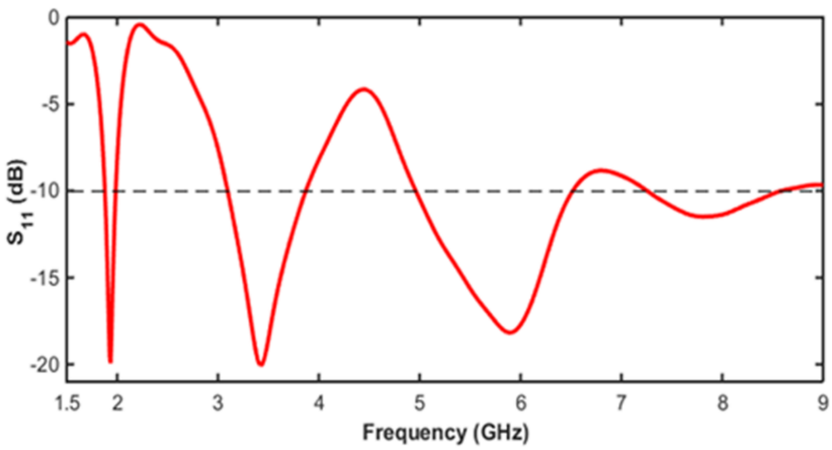

Figure 2. The simulated frequency versus reflection coefficient (S-parameter) curve.

The surface current distributions of the antenna calculated in the simulation at 1.936 GHz, 3.43 GHz, 5.9 GHz and 7.8 GHz are illustrated in Figure 3. The larger one indicates surface current distributions in red, and the smaller one in blue. As can be seen from the results, the current distributions of the frequencies are different from each other. For the lowest frequency band at 1.936GHz, it is seen that the surface currents are more concentrated on the long arm patch radiator and some parts of the short patch (Figure 1a). However, on the higher resonant frequency bands, generally decreasing density of surface currents is observed. As shown in Figure 3b, the current at 3.43 GHz frequency is concentrated on the short arm of the patch, especially on the vertical conductor between the horizontal conductors, and there is also partial current density on the microstrip feed line close to the patch. As seen in Figures 3c and 3d, current densities are close to homogeneous on the microstrip feed line and patches. The current density at 5.9 GHz is slightly more concentrated on the upper horizontal

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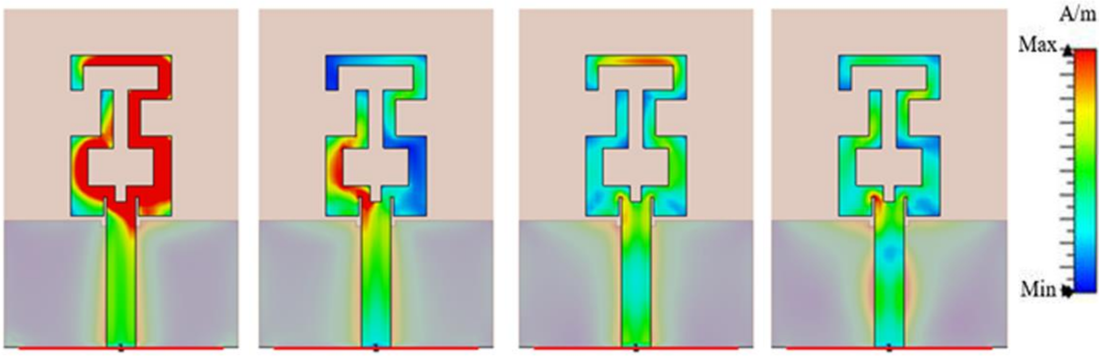
conductor of the long arm of the patch and the microstrip feedline than in the other parts of the antenna.



(a) (b) (c) (d)

Figure 3. Simulated surface current distributions for different operating frequency bands of the antenna. (a) 1.936 GHz (b) 3.43 GHz (c) 5.9 GHz (d) 7.8 GHz.

Figure 4 illustrates the simulated far-field radiation patterns for the antenna in the polar coordinate system at 1.936 GHz, 3.43 GHz, 5.9 GHz, and 7.8 GHz maximum resonance frequencies. The solid and dash lines are phi=0° and phi=90°, respectively. As illustrated in Figure 4, the antenna exhibits omnidirectional radiation nearly dipole-liked radiation patterns at 1.936 GHz, 3.43 GHz (Figure 4a and 4b) and very close to omnidirectional at 5.9 GHz and 7.8 GHz (Figure 4c and 4d). It can be seen that the radiation patterns are somewhat distorted towards the upper resonance frequencies. This may be due to the asymmetrical patch of the proposed antenna and the excitation of higher-order resonance modes. However, it still has an omnidirectional radiation pattern acceptable for vehicle applications. An antenna with an omnidirectional radiation pattern is highly preferred in wireless vehicle communication systems since it provides signal communication from all directions.

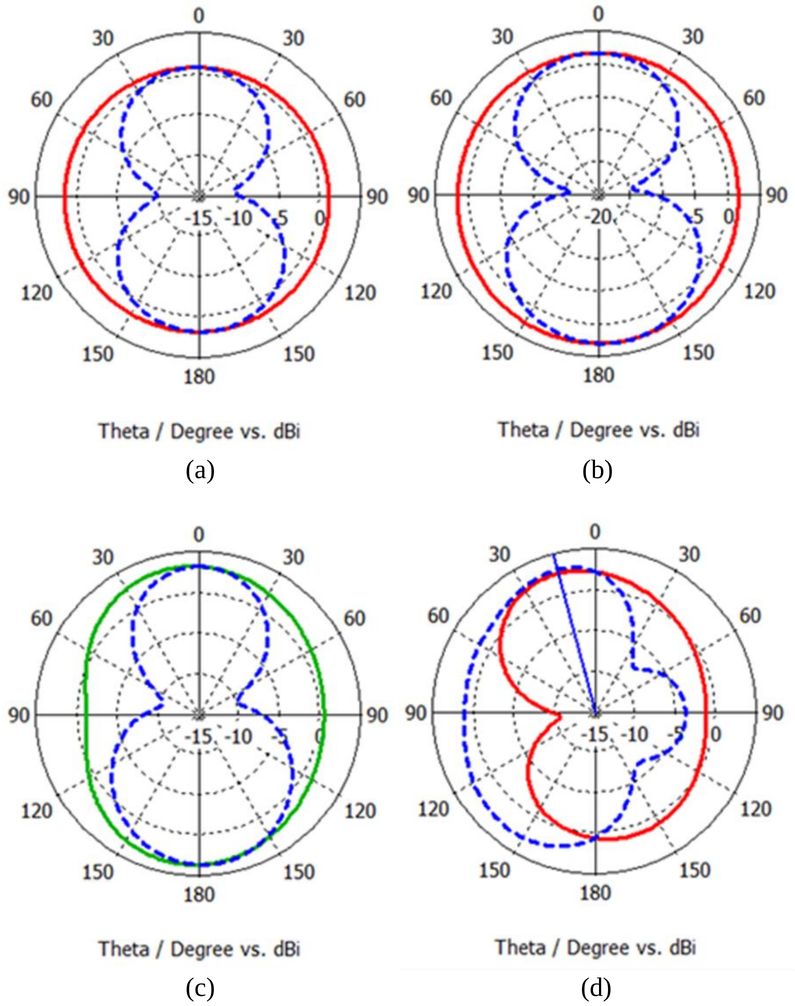


Figure 4. Simulated far-field directivity radiation pattern (—— Phi:0°, - - - - Phi:90°) of quad band antenna at(a) 1.936 GHz, (b) 3.43 GHz, (c) 5.9 GHz, and (d) 7.8 GHz.

Figure 5 illustrates the variation of the simulated gain with the frequency of the quad-band compact printed antenna for all operating quad-frequency bands. The simulated maximum gains variation of the antenna are -0.16–0.61 dBi, 1.76–2.16 dBi, 1.87–2.6 dBi, and 2.5–3.3 dBi in 1.879–1.986 GHz, 3.10–3.87 GHz, and 4.97–6.515 GHz, respectively. In addition, the gains at operating frequencies of 1.936 GHz, 3.43 GHz, 5.2 GHz, 5.5 GHz, 5.8 GHz, 5.9 GHz, and 7.8 GHz are about 0.34 dBi, 1.97 dBi, 2.05 dBi, 2.30 dBi, 2.50 dBi, 2.55 dBi, and 2.74 dBi, respectively. The reason why the gain is low or negative is because the antenna ground plane and dimensions are small in terms of electrical size (λ) as wavelength in free space. There is a similar situation in the literature [25][26]. In fact, these antennas in the literature[25][26] are lower and have negative gain. For example, in [25] the antenna gains are -6 dBi, -4 dBi, 2.5 dBi, 5 dBi and 4 dBi at 1.5 GHz, 3 GHz, 5.5 GHz, 9.5 GHz and 11 GHz, respectively. This proposed antenna exhibits acceptable gains at GSM 1900 GHz, WiMAX 3.5/5.5 GHz, WLAN 5.2/5.8 GHz, DSRC 5.9 GHz, and X-band satellite (7.26 - 8.6 GHz) operating bands, which makes it suitable for practical vehicle applications.

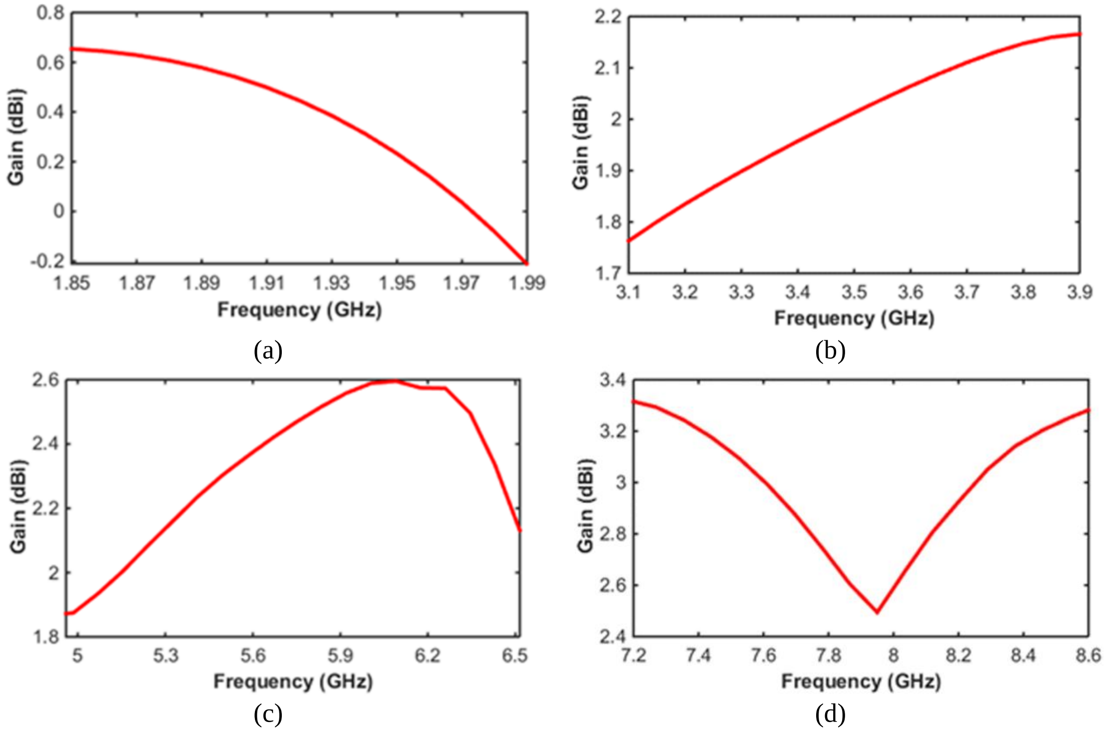


Figure 5. Simulated gain of quad band antenna at (a) GSM 1.900 GHz, (b) WiMAX 3.5 GHz, (c) WLAN 5.2/5.8 GHz, WiMAX 5.5 GHz, and DSRC 5.9 GHz, (d) X-Band 7.26 - 8.6 GHz.

Figure 6 illustrates the variation of the simulated radiation efficiency result for the antenna. The radiation efficiencies are about 60%, 82%, 77%, and 72% at the lower, second, third and higher frequency bands, respectively. According to these results, the antenna radiation efficiency is at a suitable level for vehicle communication applications.

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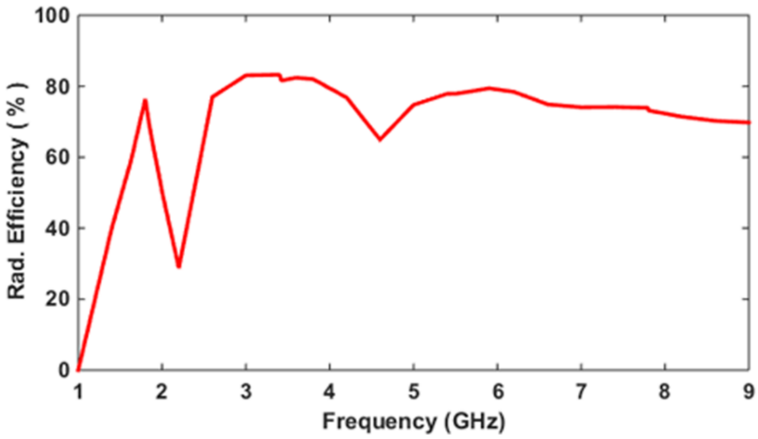

Figure 6. Simulated radiation efficiency variation with the frequency of quad band antenna.

A performance comparison between the design antenna and the multi-band reference antennas in the literature for size, number of operating frequency bands, and gain characteristics are given in Table 2. The design presented in the table seems to be very advantageous compared to other reference antennas in terms of electrical size (λ) as wavelength in free space and operation frequency band numbers. Only reference[20] is equal to the recommended antenna, but its size and gain are smaller than recommended. In addition, in terms of gain, the proposed antenna is higher than the ref [19-22, 24] antennas and is close to the gain of the reference[23] antenna. From Table 2, it is evident that the quad-band antenna provides decent gains in a simple structure with a small size for vehicle communication in GSM 1.900 GHz, WiMAX 3.5/5.5 GHz, WLAN 5.2/5.8 GHz, DSRC 5.9 GHz, and X-band applications.

Table 2. Performance comparison of dimensions, resonant frequency, number of bands and gain.

Ref.	**Antenna Dimensions (mm/ λ)**	**Resonant Frequency (GHz)**	**Num. of Band**	**Gain (dBi)**	**Applications**
[19]	45.5 × 20.8 × 1.6 FR4 0.388 λ × 0.177 λ × 0.013 λ	2.20 – 2.92 3.22 – 4.39 5.08 – 6.79	Tri Band	2.15 2.42 1.08	WLAN, WiMAX
[20]	30 × 24.8 × 1.6 FR4 0.309λ × 0.255λ × 0.016λ	3.04 – 3.15 5.44 – 5.72 6.76 – 7.72 9.42 – 9.98	Quad band	1.35 1.0 1.07 1.75	WiMAX, Satellite TV, and X-Band
[21]	35 × 30 × 1.6 FR4 0.29λ × 0.254λ × 0.013λ	2.41 – 2.56 3.12 – 3.18	Dual band	1.05 1.09	WLAN, WiMAX

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[22]	50 × 40 × 1.6 FR4 0.395λ × 0.316λ × 0.012λ	1.85 – 2.90 4.90 – 5.50	Dual band	2.3 3	3G, 4G, WLAN, and Bluetooth
[23]	36 × 39 × 1.6 FR4 0.294 λ × 0.318 λ × 0.013 λ	2.35 – 2.52 3.20 – 4.16 5.13 – 5.87	Tri band	1.14 – 1.69 2.41 – 2.79 2.68 – 4.02	WLAN WiMAX
[24]	56 × 56 × 1.6 FR4 0.35λ × 0.35λ × 0.01 λ	1.75 – 2.0 3.01 – 4.18	Dual band	1.5 2.05	GSM and 5G (sub-6-GHz)
Our Design	36 × 25 × 1.6 FR4 0.232 λ × 0.161 λ × 0.01 λ	1.879 – 0.986 3.100 – 3.87 4.970 – 6.515 7.260 – 8.60	Quad band	-0.16 – 0.61 1.76 – 2.16 1.87 – 2.6 2.50 – 3.3	GSM, WLAN, WiMAX, DSRC and X-bands

4. CONCLUSIONS

This article proposes a microstrip fed planar multi-band antenna for vehicular communication applications. The antenna has two branches of curved strips shaped radiator for multi-band response and is designed on an FR4 dielectric with dimensions of 36 × 25 × 1.6 mm3. The antenna is designed and optimized through the 3D electromagnetic simulation software program, and the antenna reflection coefficient, directivity, and gain parameters simulation results are presented successfully. The proposed design antenna offers four resonance frequency bands from 1.879 to 1.986, 3.10 to 3.86 GHz, 4.97-6.515GHz and 7.26-8.60 GHz, cover many applications like GSM1900, WLAN, WiMAX, DSRC and X-bands. These bands have acceptable gains and nearly omnidirectional radiation properties for vehicle applications and many other applications. In addition, since the antenna is simple and small size design, it can be easily produced with an electronic printed circuit technique and can be easily integrated into different parts of the vehicle. With these advantages, the design is thought to offer good performance for modern multi-band wireless vehicle communication system applications.

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The authors declare that they have no conflict of interest.

REFERENCES

[1] Tripathi, S., Pathak, N. P. and Parida, M., (2018), Dual-band dual-beam microstrip patch antenna for intelligent transportation systems application, In 2018 5th IEEE Uttar Pradesh Section International Conference on Electrical, Electronics and Computer Engineering (UPCON), IEEE 2-4 November, 2018, 1–5.

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Journal of Scientific Reports

[2] Malathy, E.M., Praveen Joe, I.R. and Ajitha, P., (2021), Miniaturized dual-band metamaterial-loaded antenna for heterogeneous vehicular communication networks, IETE Journal of Research, 1-10.

[3] Prasojo, J. and Sarno, R., (2020), Hexagonal patch microstrip antenna with parasitic element for vehicle communication, In: 2020 International Seminar on Application for Technology of Information and Communication (iSemantic), IEEE 2020, 340–345.

[4] Hakanoglu, B.G., Koc, B., Sen, O., Yalduz ,H. and Turkmen, M., (2021), Stub loaded patch antenna and a novel method for miniaturization at sub 6 GHz 5G and Wi-Fi frequencies, Advances in Electrical and Computer Engineering, 21, 23–32.

[5] Santos, M.V., Faria, S.M.M. and Fernandes, T.R., (2021), A simple slot Antenna for vehicle to infrastructure communication using 802.11 p, In: 2021 Telecoms Conference (ConfTELE), IEEE 2021, 1–5.

[6] Wen, L., Gao, S., Luo, Q., Hu, W. and Yin, Y., (2020), Wideband dual circularly polarized antenna for intelligent transport systems, IEEE Transactions on Vehicular Technology, 69, 5193–5202.

[7] Zabri, S.N., Salleh, N.M., Abu, M. and Mohamad, S.Y., (2017), Study of a flexible antenna for intelligent transport system application, In: 2017 IEEE Asia Pacific Microwave Conference (APMC), IEEE 2017, 1357–1360.

[8] Mahendran, K., Gayathri, R. and Sudarsan, H., (2021), Design of multi band triangular microstrip patch antenna with triangular split ring resonator for S band, C band and X band applications. Microprocessors and Microsystems, 80, 103400.

[9] Anilkumar, T., Madhav, B.T.P., Rao, M.V. and Nadh, B.P., (2020), Bandwidth reconfigurable antenna on a liquid crystal polymer substrate for automotive communication applications, AEU-International Journal of Electronics and Communications, 117, 153096.

[10] Sarwar, S.M., Chowdhury, M.F.F. and Das, H.S., (2019), A dual band shark sin integrated vehicle antenna for 5G and Wi-Max applications, In: 2019 IEEE International Conference on Telecommunications and Photonics (ICTP), IEEE 2019, 1–4.

[11] Rao, T.R., (2017), Design and performance analysis of a penta-band spiral antenna for vehicular communications, Wireless Personal Communications, 96, 3421–3434.

[12] Joshi, M.P. and Gond, V.J., (2019), Design and analysis of microstrip patch antenna for WLAN and vehicular communication, Progress In Electromagnetics Research C, 97, 163–176.

[13] Gao, S., Ge, L., Zhang, D. and Qin, W., (2018), Low-profile dual-band stacked microstrip monopolar patch antenna for WLAN and car-to-car communications, IEEE Access, 6, 69575–69581.

[14] Madhav, B.T.P., Anilkumar, T. and Kotamraju, S.K., (2018), Transparent and conformal wheel-shaped fractal antenna for vehicular communication applications, AEU-International Journal of Electronics and Communications, 91, 1–10.

[15] Kishore, N., Prakash, A. and Tripathi, V.S., (2016), A multi-band microstrip patch antenna with defected ground structure for its applications, Microwave and optical technology letters, 58, 2814–2818.

[16] Agarwal, S. and Sharma, A., (2020), A miniaturized wideband antenna for vehicular communication, wimax, and wlan applications, In: 2020 International Conference on Radar, Antenna, Microwave, Electronics, and Telecommunications (ICRAMET), IEEE 2020, 151–154.

[17] Varum, T., Matos, J.N., Pinho, P. and Oliveira, A., (2012), Printed antenna for DSRC systems with omnidirectional circular polarization, In: 2012 15th International IEEE Conference on Intelligent Transportation Systems, IEEE 2012, 475–478.

[18] Patanvariya, D.G. and Chatterjee, A., (2019), Design of two-element circularly polarized bubbled antenna for vehicular communication, In: 2019 IEEE 16th India Council International Conference (INDICON), IEEE 2019, 1–4.

[19] Tangthong, N., Moeikham, P. and Akatimagool, S., (2016), A compact multi band CPW-Fed monopole antenna using L-shaped and straight slots, In: 2016 13th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON), IEEE 2016, 1–4.

[20] Ali, T., Aw, M.S. and Biradar, R.C., (2018), A fractal quad-band antenna loaded with L-shaped slot and metamaterial for wireless applications, International Journal of Microwave and Wireless Technologies, 10, 826–834.

[21] Singh, G., Kanaujia, B.K., Pandey, V.K., Gangwar, D. and Kumar, S., (2019), Design of compact dual-band patch antenna loaded with D-shaped complementary split ring resonator, Journal of Electromagnetic Waves and Applications, 33, 2096–2111.

[22] Ran, X., Yu, Z., Xie, T., Li, Y., Wang, X. and Huang, P., (2020), A novel dual-band binary branch fractal bionic antenna for mobile terminals, International Journal of Antennas and Propagation, 2020, Article ID 6109093.

[23] Wang, S., Kong, F., Li, K. and Du, L., (2021), A planar triple-band monopole antenna loaded with an arc-shaped defected ground plane for WLAN/WiMAX applications, International Journal of Microwave and Wireless Technologies, 13, 381-389.

[24] Patel, U., Upadhyaya, T., Desai, A., Pandey, R. and Pandya, K., (2022), Dual-band compact split-ring resonator-shaped fractal antenna with defected ground plane for sub-6-GHz 5G and global system for mobile communication applications, International Journal of Communication Systems, 35, e5105.

[25] Bod, M., Hassani, H.R. and Taheri, M.S., (2012), Compact UWB printed slot antenna with extra bluetooth, GSM, and GPS bands, IEEE Antennas and Wireless Propagation Letters, 11, 531-534.

[26] Li, H., Zhou, Y., Mou, X., Ji, Z., Yu, H. and Wang, L., (2014), Miniature four-band CPW-fed antenna for RFID/WiMAX/WLAN applications, IEEE Antennas and Wireless Propagation Letters, 13, 1684-1688.