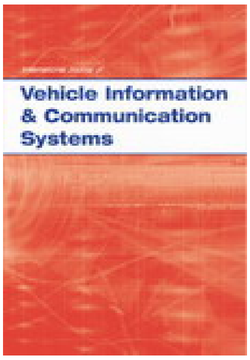


International Journal of Vehicle Information and Communication Systems

ISSN online: 1741-8208 - ISSN print: 1471-0242
https://www.inderscience.com/ijvics

Performance analysis of pentagonal MIMO antenna with elliptical slots for 5G V2V communication

A. Amsaveni, L. Harish, S. Rashmi, A. Kaiser

DOI: 10.1504/IJVICS.2023.10059209

Article History:

Received:	31 March 2023
Last revised:	14 June 2023
Accepted:	29 June 2023
Published online:	25 January 2024

Performance analysis of pentagonal MIMO antenna with elliptical slots for 5G V2V communication

A. Amsaveni*, L. Harish,
S. Rashmi and A. Kaiser

Department of Electronics and Communication Engineering,
Kumaraguru College of Technology,
Coimbatore, Tamil Nadu, India
Email: amsaveni.a.ece@kct.ac.in
Email: harishinlgh112@gmail.com
Email: rashmisuresh1504@gmail.com
Email: kaiser31a@gmail.com
*Corresponding author

Abstract: The purpose of this research is to develop a slotted pentagonal MIMO antenna specifically for 5G Vehicle-to-Vehicle (V2V) communication. The proposed antenna takes the shape of a pentagon with elliptical slots, and the feed is positioned slightly away from the centre to optimise gain. V2V communication relies on antennas that can effectively capture signals even while in motion within a vehicle. The proposed antenna supports dual operating bands, enabling it to operate in the required frequency ranges. In the 5G frequency spectrum, the antenna achieves a maximum gain of 7.34 dB, which can significantly enhance V2V communication capabilities. The presence of elliptical slots enables the antenna to focus the transmitted and received signals in specific directions, improving signal strength, directivity, coverage and overall system performance. These characteristics make it well-suited for enabling reliable and efficient V2V communication in the context of 5G networks.

Keywords: V2V; 5G frequency bands; MIMO; antenna; communication.

Reference to this paper should be made as follows: Amsaveni, A., Harish, L., Rashmi, S. and Kaiser, A. (2024) ‘Performance analysis of pentagonal MIMO antenna with elliptical slots for 5G V2V communication’, *Int. J. Vehicle Information and Communication Systems*, Vol. 9, No. 1, pp.103–113.

Biographical notes: A. Amsaveni is a Professor in the Department of Electronics and Communication Engineering at Kumaraguru College of Technology, Coimbatore. She obtained her PhD degree from Anna University, Chennai in 2016. Her research interests include antenna design, information security and signal processing.

L. Harish is a Multi-Faceted Undergraduate student at Kumaraguru College of Technology who engages in a variety of thoughtful activities particularly focusing on building skills and knowledge in the fields of embedded systems and IoT, aiming to strengthen the technical expertise.

S. Rashmi is an Undergraduate student in Electronics and Communication Engineering at Kumaraguru College of Technology. Her research interests are based on her fascination for how things work around and reality shape each other. She has been exploring electronics from different perspectives in both her research and projects.

A. Kaiser is an Undergraduate ECE student at Kumaraguru College of Technology aiming to pursue a challenging career and be part of a progressive organisation that gives a scope to enhance his knowledge, and skills and to reach the pinnacle in the electronics field with sheer determination, dedication and hard work.

1 Introduction

Vehicles in this era are designed with a high profile to meet the demands of technical advancements. Vehicle-to-vehicle communication is the paradigm that allows a vehicle to transmit and receive signals from the other vehicle to seamlessly communicate in a wireless network. This communication is mostly achieved in the Wi-Fi network of the 5G frequency band spectrum with frequencies ranging from 5 to 6 GHz. Patch antennas are widely utilised in the design of antennas due to their compact size, simple design process, and ease of fabrication. The feed assignment to the probes can also be easily determined for patch antennas. In modern communication systems, there is a growing demand for miniature antennas that exhibit multiband characteristics. However, the challenge lies in accommodating these antennas within limited space and specific locations.

To address this issue, one approach is to incorporate the concept of Multiple-Input Multiple-Output (MIMO) into the antenna geometry. By doing so, an antenna can be developed to serve multiple functions simultaneously. Utilising specific antenna designs can bring about several advantages such as downsizing, multiband/wideband capabilities and enhanced efficiency. In the realm of vehicle communications, transmitting and receiving antennas have traditionally been confined to the vehicle's roof. This necessitates the adoption of multiple antenna approaches to achieve benefits like diversity, beamforming and spatial multiplexing.

A pentagonal fractal patch antenna for multiband wireless applications has been proposed. The proposed antenna used proximity coupling feeding techniques. The antenna exhibited radiation at multiple bands of frequencies. The antenna has its radiation at 1.82 GHz and 2.45 GHz. The proposed antenna exhibited a good radiation pattern and was found to be useful in non-line-of-sight applications (Abraham et al., 2014; Amsaveni and Anusha, 2017). The design in Malik et al. (2018) achieves a super wideband of frequencies. A star-shaped microstrip patch antenna has been designed to implement 5G applications. At higher resonant frequencies above 110 GHz, it has been observed that the VSWR is comparatively lower when compared with other frequency bands.

A Hexagonal Fractal Antenna having radiation at a multiband of frequencies has been proposed. A partial ground has been designed in such a way as to minimise return loss. A microstrip transmission – line feed technique has been used to feed the proposed antenna. The offset feed is found to be good for all the parameters when compared with the centre-fed antenna (Gundala et al., 2019). A multiband antenna has been proposed to cover all the LTE frequency bands to meet IEEE 802.11 standard applications (Bustamante et al., 2017). The structure of the antenna is a modified monopole with a circular radiator. The maximum gain attained from the proposed design is 6.57 dBi at 5.9 GHz.

A hexagonal microstrip patch antenna for vehicle-to-vehicle communication has been proposed. The antenna (Honggang et al., 2016) is defined for the frequency range of 5.85 to 5.925 GHz. A coaxial probe connector is used to give feed. The relative bandwidth for the antenna is found to be 37.8 %. The stacked patch antenna has been proposed by Lee et al. (2019). The antenna operates at two distinct frequencies, specifically 5.85 GHz and 27.5 GHz. The feed has been given at one layer that has been stacked below another and Rogers RT duroid 5880 layers have been used.

A vehicle network strategy for Vehicle to Everything Communication has been discussed in the paper (Rasheed et al., 2020). 5G mm-Wave is used in V2X communication. When distributing the antenna across different sectors within a cell, it has been observed that segmenting the area yields optimal efficiency. A pentagonal-shaped truncated microstrip patch antenna has been proposed. It is noticed that the antenna has a gain of 6.8 dBi because of its feed position. The antenna radiates at 2.4 GHz. From a truncated side to a triangular slot, the latter is said to have more influence on performance (Gupta et al., 2013). A hexagonal antenna with elliptical slots has been proposed in this paper. They have designed the antenna to operate in the frequency range of 5.85 to 5.926 GHz (IEEE 802.11p). The slots in the hexagonal plane have been made by the DGS pattern. This achieves a maximum gain of 6.09 dBi (Singhal et al., 2020).

Panem et al. (2020) and Arur et al. (2019) explored the enhancement of MIMO channel capacity through the utilisation of Principal Component Analysis (PCA) data reduction methods in conjunction with Quadrature Phase Shift Keying (QPSK) modulation. The authors discuss the application of PCA for reducing the dimensions of MIMO channel data, leading to improved capacity. Panem et al. (2016) focused on the development of a data fusion architecture for sensor data integration over Multiple-Input Multiple-Output (MIMO) systems.

A compact MIMO antenna system with a MAZE-shaped design has been designed and developed. The system consists of four equally spaced elements arranged in an orthogonal configuration. The antenna achieves tri-band operation in the frequency bands of 2.25–2.41 GHz, 3.36–3.65 GHz and 4.7–6.25 GHz. It exhibits an average isolation of 20 dB, an average peak gain of 2.96 dB within the operational bands, and an efficiency of 88%. The incorporation of orthogonality eliminates the need for an additional decoupling network, thereby reducing the antenna’s complexity and size (Pamungkas et al., 2021).

In dense urban environments, Vehicle-to-Vehicle (V2V) communications often face significant keyhole fading effects, particularly in mimo channels. These fading effects can lead to a reduction in capacity and outage performance due to rank deficiency. To overcome these challenges, the integration of MIMO and Hybrid Automatic Repeat Request (HARQ) is proposed as a solution to enhance V2V communications (Naidu et al., 2021; Zhang et al., 2022).

2 Antenna configuration

In this research, it is proposed to design a MIMO-based Pentagonal Patch Antenna for 5G V2V Communication in a dual-band configuration. The equations to obtain Elliptical Slots in the Pentagonal Patch with multiple feed points given to the antennae are discussed below.

2.1 Design equations

The Pentagonal MIMO antenna is a compact and versatile antenna design that offers multiple antennas within a single structure. It consists of a pentagonal-shaped radiating element with an array of elliptical slots. Elliptical slots play a crucial role in the design of the Pentagonal MIMO antenna, contributing to its performance and characteristics. The antenna geometry is carefully designed to provide enhanced performance characteristics, such as high gain, wide bandwidth and polarisation diversity. The ground plane of the antenna (circular patch) feeds the patch conductor through the substrate FR-4 epoxy to reduce the current density (Amsaveni et al., 2019; Amsaveni, 2017). The paper gives out a design to form a circular patch modified as a pentagonal structure. The relation between the circular patch $\left(r_{cir}\right)$ and hence the pentagon $\left(r_{pen}\right)$, where the pentagon patch is marked, to achieve equivalent areas is given by the equation:

Radius of pentagon

$$r_{pen}^2 = \frac{\pi r_{cir}^2}{2.37} \tag{1}$$

Side length of pentagon

$$a = 2r_{pen} \sin\frac{\pi}{n} \tag{2}$$

The relation between radius and wavelength is given by

$$r_{pen} = \frac{\lambda}{\pi} \tag{3}$$

The operating wavelength is given by the equation

$$\lambda = \frac{v}{f_{res}\sqrt{\varepsilon_{rel}}} \tag{4}$$

where f_{res} – resonant frequency, ε_{rel} – relative permittivity, λ – wavelength of the antenna.

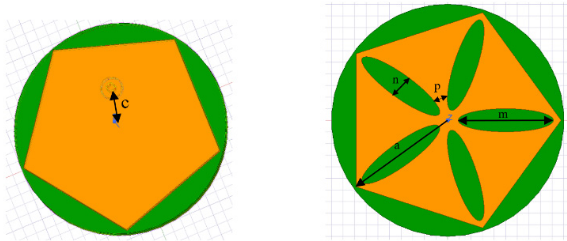
2.2 Antenna specifications

The proposed antenna has an FR-4 substrate with a dielectric constant, $\varepsilon_r = 4.2$ and thickness, h = 1 mm. The antenna is excited by using an SMA coaxial feed line centred and offset-centred with c = 8 mm from the centre of input as shown in Figure 1.

Table 1 Dimensions of the designed antenna

Parameters	*Value (mm)*
a	19.5
p	3.5
m	16.4
n	4
c	8

Figure 1 Pentagon patch antenna (a) with offset feed (b) slotted patch (see online version for colours)

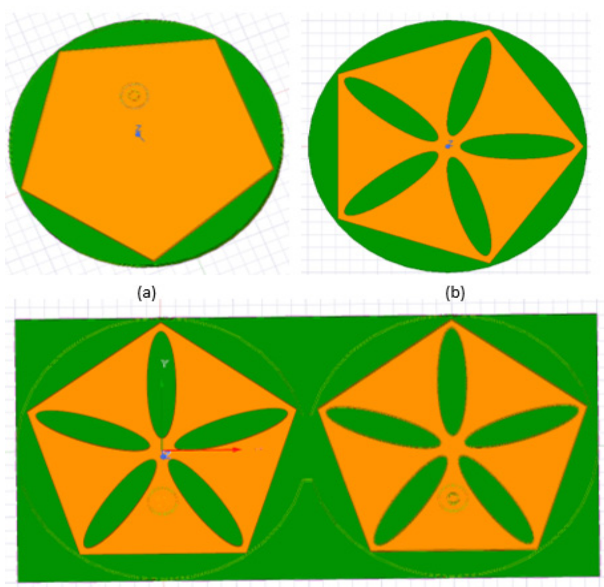


(a) (b)

2.3 Design optimisation

This research focuses on designing an antenna for 5G V2V Communication with 4.9 GHz and 5.75 GHz dual frequency bands. The design of the proposed antenna structure is attained after three main design enhancements in the regular pentagonal patch antenna structure. The basic structural design with offset feed is shown in Figure 2(a). To bring improvisation in gain and directivity elliptical slots were introduced in Figure 2(b). With further advancements, the elliptical slotted patch antenna was converted into a MIMO structure to yield greater gain and vast functionalities.

Figure 2 Development of structure (a) Antenna I (b) Antenna II (c) Antenna III (see online version for colours)



(a) (b)

(c)

The pentagonal shape allows the antenna to be compact, making it suitable for integration into various devices, including vehicles, without significant space constraints. MIMO technology improves signal quality by utilising multiple antennas to transmit and receive data simultaneously, thereby increasing the overall system capacity. The elliptical slots on the pentagonal radiating element introduce polarisation diversity, which enhances the antenna's performance in different propagation environments. It ensures reliable and robust communication links by mitigating the adverse effects of fading and interference. The design of the pentagonal MIMO antenna allows for a wide bandwidth, enabling it to support various frequency bands used in 5G V2V communication systems. The geometry of the antenna, combined with the use of multiple antennas, enables high gain. This leads to improved signal reception and transmission capabilities, allowing for extended communication range and reliable connectivity between vehicles.

3 Results and discussions

Upon analysing the antenna performance as depicted in Figure 2(a), it is evident that the obtained values were unsatisfactory, with poor S-parameter results. To improve the design parameters, an analysis of the current distribution across the surface was conducted, leading to the introduction of slots. Figure 2(b) showcases the presence of elliptical slots positioned toward the edges of the pentagonal patch. The implementation of the slotted pentagonal patch antenna yielded a significantly higher gain value of 4.34 dBi. Moreover, the S-parameter results for the desired frequencies of 4.86 GHz and 5.71 GHz were considerably lower than –20 dB. The alteration in the patch structure resulted in a substantial enhancement of the parameters at the desired frequencies. In Figure 2(c), the design incorporates a MIMO structure that utilises two identical elliptical slot antennas. This configuration further improved the gain to 7.34 dBi, with an S-parameter of –29.55 dB and a VSWR of 0.6799 at 5.71 GHz.

As in Figure 3, the obtained S-parameter values for the antenna were below the desirable range of –10 dB, indicating good transmission and reception capabilities. Additionally, the VSWR values were below 1 as shown in Figure 4, ensuring optimal antenna performance.

Figure 3 Terminal S parameter plot of the proposed antenna

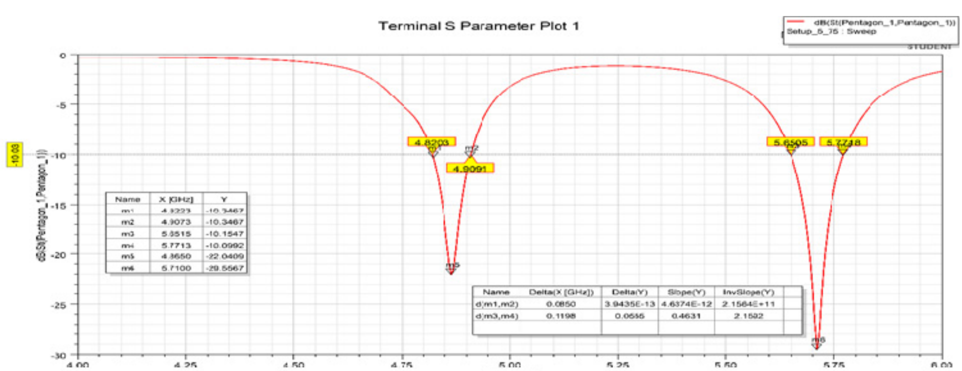


Figure 4 Terminal VSWR plot of the proposed antenna

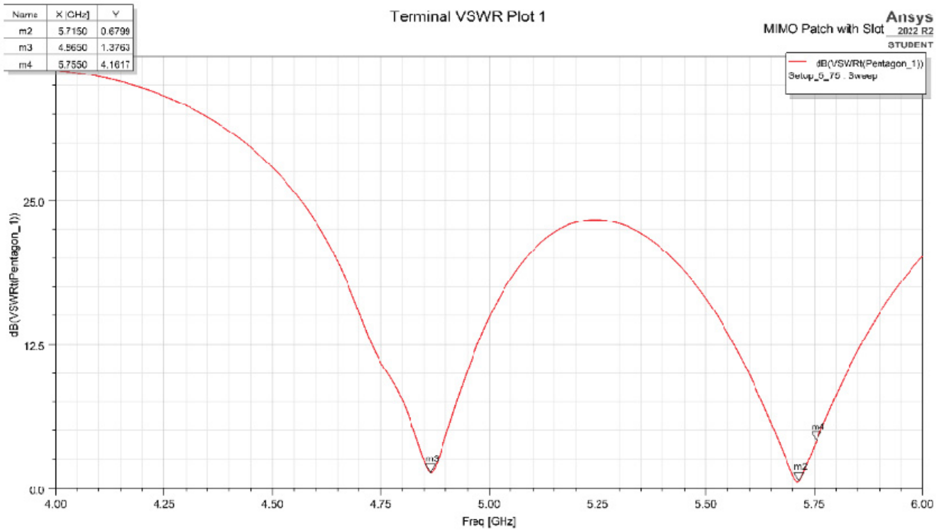
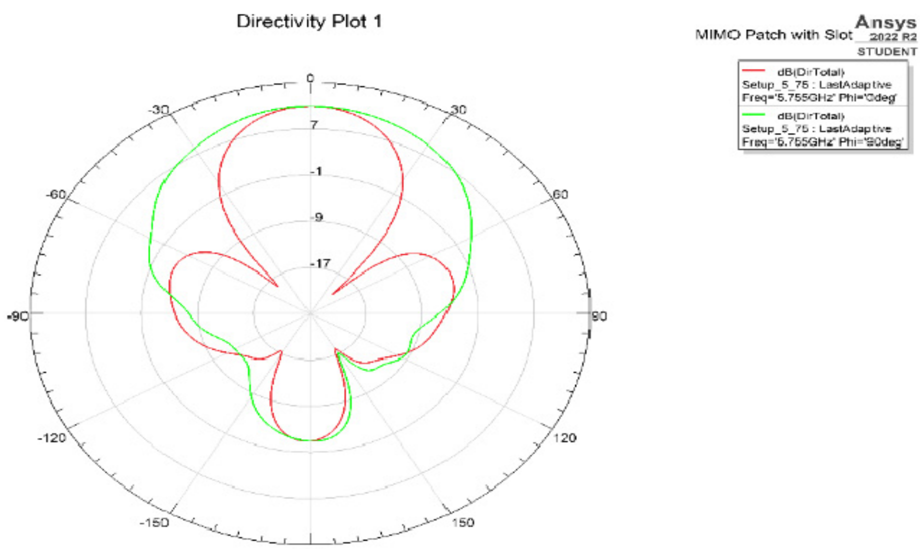
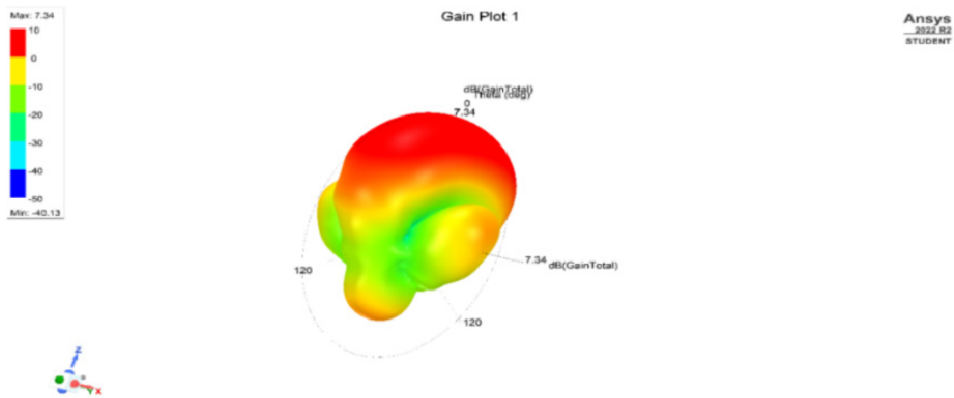


Figure 5 Directivity plot (see online version for colours)



Through the design iterations of the pentagonal patch antenna, we achieved a gain of 2.41 dBi initially. Subsequently, by implementing an offset coaxial feed line, the gain increased to 3.27 dBi. Further enhancements were made by introducing elliptical slots, resulting in a gain of 4.34 dBi. The incorporation of the MIMO structure further improved the gain to 7.34 dBi specifically at 5.71 GHz as in Figure 6. As a result of the MIMO implementation, the antenna can effectively operate in various wireless generations such as 4G and 5G, as well as in frequency bands within the ISM range (4.82 to 4.90 GHz, 5.65 to 5.77 GHz) and WLAN frequencies at 4.9 GHz and 5.75 GHz.

Figure 6 Gain plot (see online version for colours)



Minimising the current at the edge of the radiating patch is desirable to achieve optimal performance. The voltage at the patch edge is out of phase with the current, resulting in a peak in voltage and near-zero current levels at the patch's end. Similarly, a similar pattern can be observed at the centre of the wave or the start of the patch. The edges of a microstrip antenna experience field effects due to the phase difference between the voltage and current. Figure 7 illustrates the current distribution of the antenna at its resonant frequency. The incorporation of elliptical slots in the pentagonal patch results in a current distribution of up to 8.781 A/m across the surface area of the patch. The enhanced current distribution results in a notable gain improvement.

Figure 7 Current distribution (JSurf) (see online version for colours)

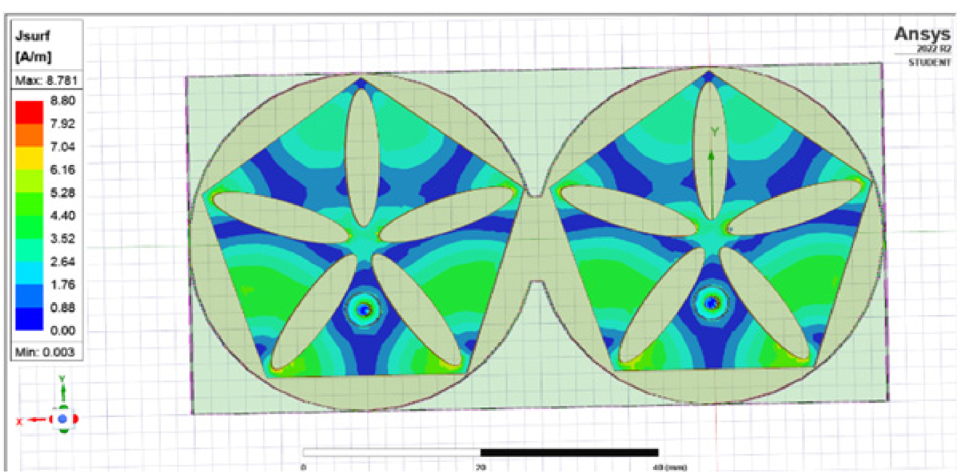


Table 2 presents the performance parameters of the proposed antenna, including radiation efficiency, gain, bandwidth, return loss and VSWR, for both operating bands. The simulation results reveal favourable performance across these parameters, indicating the antenna's effectiveness. Specifically, the antenna achieves a bandwidth of 85 MHz and 120 MHz at resonant frequencies of 4.86 GHz and 5.75 GHz, respectively. These characteristics make the antenna well-suited for applications such as Wi-Fi, WLAN and WiMAX.

Table 2 Performance of the proposed antenna at both operating bands

Parameters	*Operating Band I*	*Operating Band II*
Resonant frequency (GHz)	4.86	5.75
Radiation efficiency (%)	89.23	94.18
Gain (dBi)	7.17	7.34
Bandwidth (MHz)	85	119.8
Return loss (dB)	–22.04	–29.55
VSWR	1.37	0.67
Applications	Point-to-multi-point, base/mobile/portable operations	Network access points, Wi-Fi and Wireless LAN applications, Radio local area networks, WiMAX networks

From Table 3, it becomes clear that the proposed design outperforms other works in the literature in terms of gain and S parameters at the desired frequency.

Table 3 Comparison of antenna parameters with existing works in the literature

Performance measure	*Present work*	*Work of Malik et al. (2018)*	*Work of Rasheed et al. (2020)*	*Work of Gupta et al. (2013)*
Centre Frequency	5.71 GHz	7.3 GHz	2.45 GHz	5.9 GHz
VSWR	0.6799	1.31	1.944	–
Gain	7.34 dB	–1.72	6.833 dB	6.09
S – Parameter (S_{11})	–29.55 dB	–17.75	–20 dB	–32 dB

4 Conclusion

The proposed pentagonal dual-band MIMO antenna covers two frequency bands that are suitable for different applications in ISM bands, including WLAN, LTE Band40, WiMAX and 5G. The frequency bands span from 4.82 to 4.91 GHz and from 5.65 to 5.78 GHz, which yields a bandwidth of 85 MHz and 120 MHz, respectively. The integration of patch with elliptical slots and MIMO techniques results in a miniaturised, low-profile dual-band planar antenna suitable for 5G V2V communication and other wireless applications. The design of the antenna incorporates elliptical slots and an offset monopole ground structure, resulting in a dual-band patch antenna. The antenna's operational characteristics have been validated through simulations, demonstrating its versatility and effectiveness.

References

Abraham, J., John, K.A. and Mathew, T. (2014) 'Microstrip antenna based on pentagon fractal patch for multiband wireless applications', *Proceedings of the International Conference on Information Communication and Embedded Systems (ICICES2014)*, IEEE, pp.1–5.

Amsaveni, A. (2017) *Antennas and Wave Propagation*, *Anuradha Publications*, Chennai.

Amsaveni, A. and Anusha, K. (2017) 'A circularly polarized triangular slot reconfigurable antenna for wireless applications', *Int J Pure Appl Math*, Vol. 116, No. 11, pp.81–89.

Amsaveni, A., Bharathi, M. and Swaminathan, J.N. (2019) 'Design and performance analysis of low SAR hexagonal slot antenna using cotton substrate', *Microsystem Technologies*, Vol. 25, No. 6, pp.2273–2278.

Arur, P.C., Chodankar, D. and Gad, R.S. (2019) 'MIMO channel capacity enhancement using PCA data reduction methods with QPSK modulation', *Proceedings of the IEEE International Conference on Distributed Computing, VLSI, Electrical Circuits and Robotics (DISCOVER)*, IEEE, pp.1–4.

Bustamante, A., Inca, S., Chuchon, M., Adriano, R. and Samaniego, J. (2017) 'Design of a V2V communications antenna based on LTE technology and IEEE802. 11p standard', *Proceedings of the IEEE 24th International Conference on Electronics, Electrical Engineering and Computing (INTERCON)*, IEEE, pp.1–4.

Gundala, S., SrinivasaBaba, V.S.S.N., Vijaya, A. and Machanna, S. (2019) 'Compact High Gain Hexagonal Fractal Antenna for 5G applications', *Proceedings of the IEEE International Conference on Advanced Networks and Telecommunications Systems (ANTS)*, IEEE, pp.1–7.

Gupta, Y.K., Yadava, R.L. and Yadav, R.K. (2013) 'Circularly polarized truncated pentagonal-shaped Microstrip patch antenna', *International Journal of Microwaves Applications*, Vol. 6, No. 6, pp.149–152.

Honggang, H., Jiayu, L., Daili, H. and Wei, L. (2016) 'Design of hexagon microstrip antenna for vehicle-to-vehicle communication', *The Journal of China Universities of Posts and Telecommunications*, Vol. 23, No. 4, pp.69–76.

Lee, W., Hong, Y. K., Won, H., Choi, M., Jeong, N. S. and Lee, J. (2019) 'Dual□band (5G millimetre-wave and dedicated short□range communication) stacked patch antenna for advanced telematics applications', *Microwave and Optical Technology Letters*, Vol. 61, No. 5, pp.1381–1387.

Malik, R., Singh, P., Ali, H. and Goel, T. (2018) 'A star-shaped superwide band fractal antenna for 5G applications', *Proceedings of the 3rd International Conference for Convergence in Technology (I2CT)*, IEEE, pp.1–6.

Naidu, P.V., Dhanekula, M.B., Almustafa, K.M., Kumar, A., Meerja, K.A. and Akkapanthula, S.H. (2021) 'Design and performance analysis of MAZE shaped quad port ACS fed tri-band MIMO antenna for V2V and multi-band applications', *AEU-International Journal of Electronics and Communications*, Vol. 134, 153676.

Pamungkas, W., Hendry, J. and Hadiansyah, W.M. (2021) 'An improved spectral temporal average method for mitigating Doppler effects in V2V communications', *International Journal of Vehicle Information and Communication Systems*, Vol. 6, Nos. 3/4, pp.317–335.

Panem, C., Chodankar, D., Gad, R.S. and Naik, G.M. (2020) 'PCA data reduction for MIMO-based channel, capacity enhancement using 16-QAM modulation', *Universal Journal of Electrical and Electronic Engineering*, Vol. 7, No. 2, pp.118–126.

Panem, C., Gaonkar, A.A., Rane, U.V., Pandit, A.B. and Gad, R.S. (2016) 'Sensors data fusion architecture over MIMO: case study of quad copter', *International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT)*, IEEE, pp.2361–2365.

Rasheed, I., Hu, F., Hong, Y.K. and Balasubramanian, B. (2020) 'Intelligent vehicle network routing with adaptive 3D beam alignment for mm Wave 5G-based V2X communications', *IEEE Transactions on Intelligent Transportation Systems*, Vol. 22, No. 5, pp.2706–2718.

Singhal, H., Ashwin, S., Sharma, V., Prajapati, J. and Upadhayay, M.D. (2020) 'High gain hexagonal patch antenna for V2V communication', *Proceedings of the 7th International Conference on Signal Processing and Integrated Networks (SPIN)*, IEEE, pp.687–691.

Zhang, H., Liao, Z., Shi, Z., Yang, G., Dou, Q. and Ma, S. (2022) 'Performance analysis of MIMO-HARQ assisted v2v communications with keyhole effect', *IEEE Transactions on Communications*, Vol. 70, No. 5, pp.3034–3046.