

Design and prototyping of the planar inverted-F antenna for V2X communications

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ABSTRACT

In the context of intelligent transportation systems (ITS) development, vehicle-to-everything (V2X) communication plays a central role by enabling information exchange between vehicles (V2V), infrastructure (V2I), pedestrians (V2P), and the network (V2N). The effectiveness of these systems relies heavily on the performance of the antennas employed, which must meet strict requirements in terms of compactness, bandwidth, gain, and electromagnetic compatibility. One of the main challenges lies in designing antennas suitable for the embedded vehicular environment, where space is limited and the propagation conditions are complex. In this context, the present study aims to design, simulate, fabricate, and experimentally evaluate a planar inverted-F antenna (PIFA) dedicated to V2X communication in the 5.8 GHz band. The primary objective is to develop an antenna that is both compact and high-performing, tailored to the specific constraints of V2X applications. The adopted methodology involves a comprehensive parametric study, focusing on several key design parameters that influence the antenna's performance, such as substrate selection, feeding point location, and the addition of a slot in the structure. These factors are analyzed to optimize the radiation characteristics, resonant frequency, and impedance matching of the antenna. The results demonstrate the feasibility of a PIFA antenna that offers an excellent trade-off between miniaturization and performance, making it well suited for V2X communication applications at 5.8 GHz.

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1. INTRODUCTION

Planar inverted-F antennas (PIFA) are widely used in vehicle-to-everything (V2X) communication applications due to their compact design, low profile, and good electromagnetic performance. V2X technology enables vehicles to communicate with other vehicles (V2V), road infrastructure (V2I), pedestrians (V2P), and cellular networks (V2N), requiring antennas capable of reliable operation in various challenging environments such as densely populated urban areas and high-speed highways. The PIFA antenna stands out from other antenna types due to its ability to be integrated into confined spaces, such as vehicle bodies, while offering good impedance matching, adequate directional gain, and interference resistance. Its structure consists of a radiating plate placed parallel to a ground plane, connected by a short-circuit slot, allowing size reduction while maintaining performance. These features make the PIFA an ideal choice for V2X applications requiring compact antennas with good radiation performance [1].

For V2X systems, the use of industrial, scientific, and medical (ISM) frequency bands at 5.8 GHz, or dedicated intelligent transportation communication bands at 5.9 GHz, demands antennas capable of

operating precisely at these frequencies. PIFA antennas, thanks to their ability to adjust the resonant frequency by modifying the dimensions of the radiating plate and the position of the short-circuit slot, are well suited to meet these requirements. Moreover, their low manufacturing cost and design simplicity make them a practical solution for mass applications in the automotive industry [1], [2].

The contribution of this study is therefore highly significant, as it provides an optimized technical solution tailored to the specific constraints of V2X communications, which are essential for the development of intelligent transportation systems. By enhancing the compactness, robustness, and performance of onboard antennas, this research helps strengthen the reliability of information exchange between vehicles and infrastructure, a key element for road safety, traffic management, and accident reduction. Thus, optimizing PIFA antennas in the 5.8 GHz band plays a crucial role in the effective deployment of large-scale V2X technologies, promoting the transition towards smarter, connected, and more sustainable transportation networks. In summary, PIFA antennas represent an efficient and optimized solution for V2X communication needs, combining advantages in terms of size, performance, and cost. Their development and optimization for V2X applications, particularly at 5.8 GHz, constitute an active research area aimed at enhancing intelligent transportation systems and road safety [2].

2. STATE OF THE ART

2.1. V2X communications

V2X communication represents a significant advancement in the field of intelligent transportation systems (ITS) and connected mobility. It refers to a set of technologies that enable vehicles to communicate with their environment, including other vehicles (V2V), road infrastructure (V2I), pedestrians (V2P), and the global network (V2N). The goal of V2X communication is to improve road safety, traffic efficiency, and user experience by facilitating real-time information exchange [2], [3].

The development of V2X communication is driven by the growing need to reduce road accidents and congestion while promoting the transition to autonomous driving. By allowing vehicles to share information about their position, speed, and direction, V2X helps prevent collisions, manage traffic intelligently, and facilitate advanced applications such as collaborative emergency braking, lane change assistance, and platooning. V2X technologies rely on different communication standards, mainly dedicated short-range communications (DSRC) based on the IEEE 802.11p standard and C-V2X (Cellular V2X), which utilizes LTE and 5G cellular networks. Each of these technologies has specific advantages: DSRC offers low latency and direct short-range communication, while C-V2X benefits from a wider range and better integration with existing cellular infrastructures [3]–[5].

Despite the progress made, the large-scale implementation of V2X communication faces several challenges, including interoperability between different technologies, security and privacy issues, and the high costs associated with infrastructure. However, with the emergence of 5G and advancements in artificial intelligence, the future prospects for V2X are promising, paving the way for increasingly sophisticated applications and safer, more efficient mobility [6]–[8]. Figure 1 illustrates the V2X communication concept, highlighting the different modes of information exchange, namely vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-network (V2N), and vehicle-to-pedestrian (V2P), which aim to enhance road safety, traffic efficiency, and intelligent transportation services.



Figure 1. Vehicle to everything V2X [1]

2.2. Types of V2X

V2X communication is categorized into several types, each corresponding to a specific interaction between the vehicle and its environment. Here are the main types of V2X:

- a. Vehicle-to-vehicle (V2V) communication allows vehicles to exchange information directly with each other, such as position, speed, and direction. This data improves road safety by preventing collisions, alerting drivers to potential hazards (sudden braking and stopped vehicles), and facilitating applications such as collaborative emergency braking and platooning.
- b. Vehicle-to-infrastructure (V2I) allows vehicles to communicate with road infrastructure such as traffic lights, road signs, and traffic management systems. This can be used to dynamically adjust speed limits, optimize traffic lights based on vehicle flow, and provide information about road conditions. This interaction contributes to smoother traffic flow and reduced congestion [3], [9], [10].
- c. Vehicle-to-pedestrian (V2P) communication aims to improve the safety of pedestrians and cyclists by allowing vehicles to detect their presence and alert them, or vice versa. Pedestrians can use devices such as smartphones or wearables to send information to nearby vehicles, warning drivers of their presence, especially in situations where visibility is reduced [11].
- d. Vehicle-to-network (V2N) connects vehicles to a broader network, such as the cloud or service provider servers, using cellular networks (LTE, 5G). This allows access to cloud-based services, such as real-time traffic updates, weather conditions, and information about hazardous areas. V2N can also be used for entertainment services or advanced navigation functions.
- e. Vehicle-to-grid (V2G) is a type of communication where electric vehicles interact with the power grid. This communication allows vehicles to send electricity back to the grid during peak demand periods or charge their batteries when energy prices are low. V2G thus contributes to energy demand management and grid stability [4], [9], [10].
- f. Vehicle-to-device (V2D) refers to communication between the vehicle and portable devices or smart devices on board. This includes connecting with smartphones, tablets, or wearables to provide connectivity features and personalized services to drivers and passengers. Figure 2 illustrates the main types of V2X communication, including V2V, V2I, V2N, and V2P, highlighting the interaction between vehicles and their surrounding environment.

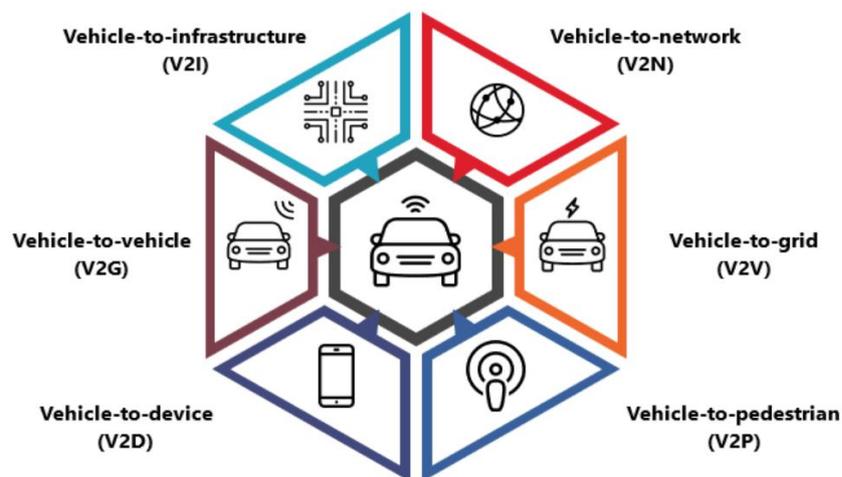


Figure 2. Types of V2X communication [1]

3. PARAMETRIC STUDY OF THE PIFA ANTENNA

The proposed antenna is a PIFA consisting of a rectangular patch, with a width of $W=20$ mm and a length of $L=18$ mm, placed on a substrate with a width of $W=30$ mm and a length of $L=30$ mm. The material used is FR4 epoxy, characterized by a relative permittivity of 4.4, a relative permeability of 1, a dielectric loss tangent ($\tan \delta$) of 0.02, and a thickness of $e=0.7$ mm. The antenna is connected to the ground plane via a strip with a height of $h=10$ mm and a width of 10 mm Figure 3.

Figure 4 shows the simulation of PIFA antennas, resonating at 5.8 GHz, yields the curves presented in Figures 4. The parameter S_{11} is given by the curve in Figure 4. We observe a peak of $S_{11}=-34$ dB around the frequency of 5.8 GHz, with a bandwidth of 350 MHz [12]–[16].

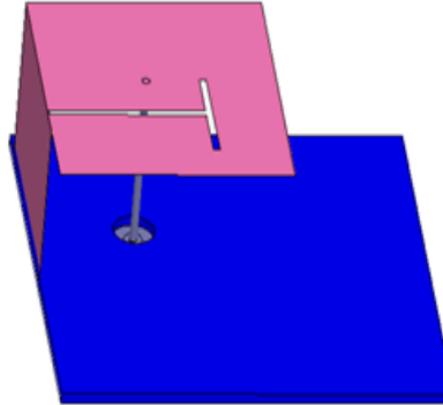


Figure 3. Design of PIFA antenna

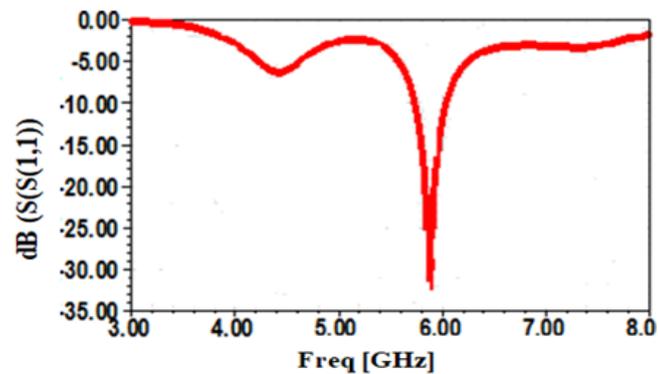


Figure 4. Return loss of PIFA antenna

4. DESIGN OF A FOLDED PIFA ANTENNA

To reduce the dimensions of our PIFA antenna, we proposed to fold the studied antenna. The study focuses on an inverted-F antenna featuring a folded metallic radiating element, connected by a short-circuit strip to a ground plane and fed via a coaxial cable. The folded PIFA antenna consists of a rectangular patch with a width of $W=20$ mm and a length of $L=18$ mm, placed on a substrate with a width of $W=30$ mm and a length of $L=30$ mm. The substrate used is FR4 epoxy, characterized by a relative permittivity of 4.4, a relative permeability of 1, a dielectric loss tangent of $\text{tg } \delta=0.02$, and a thickness of $h=0.8$ mm. The antenna is connected to the ground plane via a strip with a height of $h=10$ mm and a width of 10 mm. Figure 5 shows the geometry of the folded PIFA antenna [17]–[22].

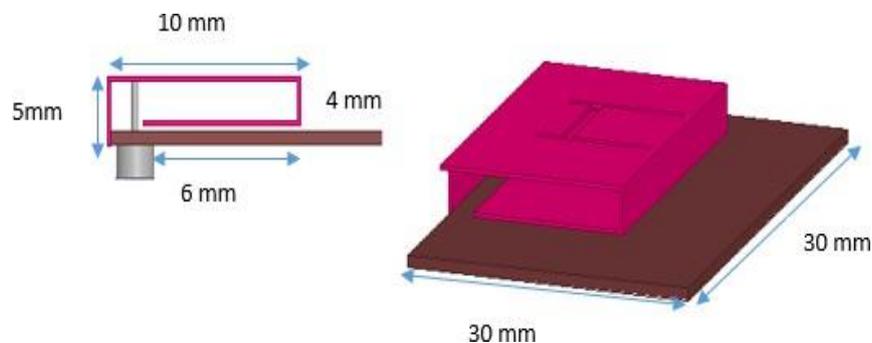


Figure 5. Design of a folded PIFA antenna

The resonant frequency is 5.8 GHz. The simulation of the antenna using Ansoft HFSS software yields the following results: The curve in Figure 6 shows the return Loss (S11) obtained for the folded PIFA antenna. A minimum S11 value of -27 dB is observed, centered around the resonance with a bandwidth of 200 MHz. Figure 7 shows that the standing wave ratio (SWR) is below 2, indicating a good impedance matching between the antenna and the transmission line. This value means that signal reflection is minimal, and the antenna efficiently radiates the transmitted energy into free space. This result confirms the reliable performance of the PIFA antenna within the target frequency band, which is essential for V2X applications [23]–[25].

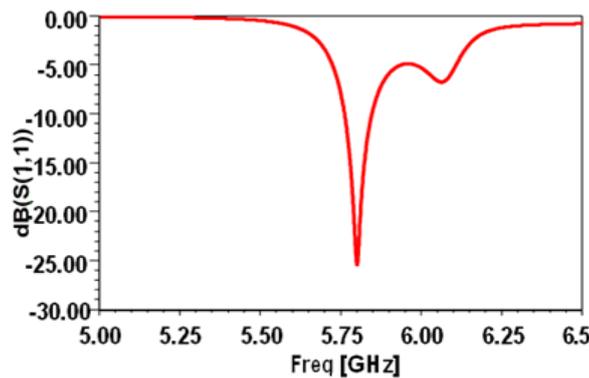


Figure 6. Return loss of a folded PIFA antenna

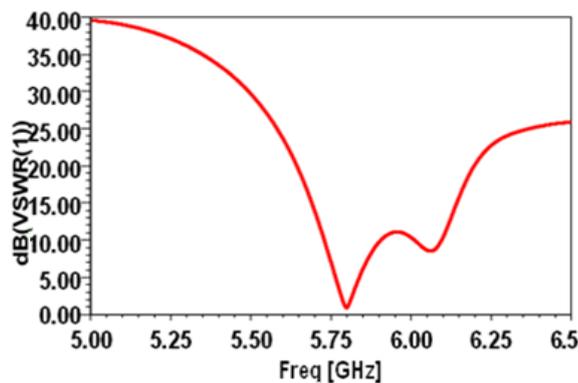


Figure 7. SWR of a folded PIFA antenna

5. PROTOTYPING OF THE PIFA ANTENNA

After the design and simulation of the antennas using the HFSS software, we proceeded to the implementation phase. The support for the printed circuit boards is a printed circuit. This consists of an epoxy plate on which copper traces are etched. The plate is made up of a protective film, resin, copper, and the substrate.

The constructed antenna is a PIFA consisting of a rectangular patch with a width of $W=26$ mm and a length of $L=30$ mm, placed on a substrate with a width of $W=35$ mm and a length of $L=40$ mm, using FR4 epoxy as the material characterized by a relative permittivity of 4.4, a relative permeability of 1, a dielectric loss tangent $\tan \delta=0.02$, and a thickness of $h=0.7$ mm. The antenna is connected to the ground plane through a tab with a height of $h=3.8$ mm and a width of 10 mm. Figure 8 shows the prototype of the constructed antenna.

We notice a good correlation between the simulated and measured results regarding the resonance frequencies and bandwidths. Figure 9 we observe that the difference between the simulated S11 and measured may be attributed to manufacturing tolerances, losses from the SMA connector, and dielectric losses of the FR4 material.

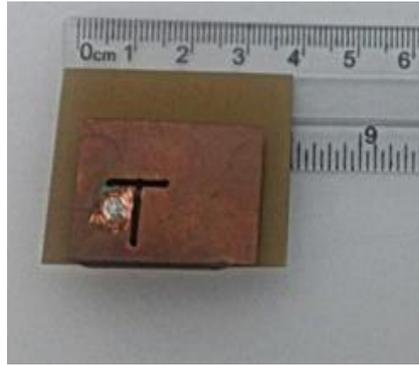


Figure 8. Prototype of the PIFA antenna

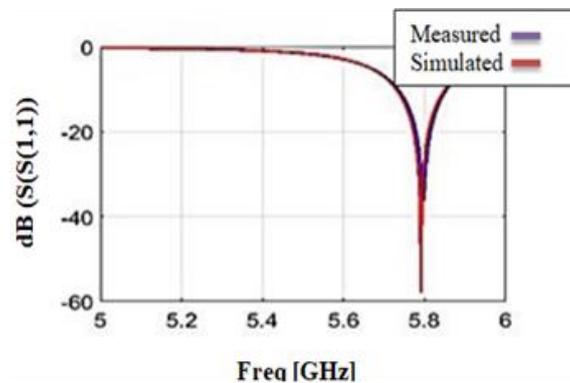


Figure 9. The measured and simulated return loss of the PIFA antenna

6. CONCLUSION

In this article, we presented the design and realization of a planar inverted-F antenna (PIFA) specifically adapted for V2X applications. Through a thorough parametric study, we analyzed various factors influencing the antenna's performance, such as geometry, substrate choice. The results obtained show a good correlation between the simulations carried out using HFSS software and the experimental measurements performed on the prototype. The resonant frequency of 5.8 GHz was achieved with a minimal reflection coefficient, indicating optimal matching. The performance in terms of bandwidth and gain also meets the specific requirements for V2X communications.

The antenna design took into account size and integration constraints within vehicles, demonstrating its suitability for modern applications. In conclusion, this study shows that the PIFA antenna is an effective solution for enhancing connectivity in V2X systems, thereby contributing to road safety and traffic fluidity. Future work could explore optimizing the design for specific use V scenarios and integrating advanced technologies for even better performance.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Loubna Berrich	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Adnane Addaim		✓		✓	✓					✓		✓		

C : Conceptualization	I : Investigation	Vi : Visualization
M : Methodology	R : Resources	Su : Supervision
So : Software	D : Data Curation	P : Project administration
Va : Validation	O : Writing - Original Draft	Fu : Funding acquisition
Fo : Formal analysis	E : Writing - Review & Editing	

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

REFERENCES

- [1] K. Nasr and K. Sarabandi, "A low-cost millimeter-wave 5G V2X multi-beam dual-polarized windshield antenna," *IEEE Open Journal of Antennas and Propagation*, pp. 1313–1323, 2022, doi: 10.1109/OJAP.2022.3224807.
- [2] L. K. Chung *et al.*, "Three-element circularly polarized MIMO antenna with self-decoupled probing method for B5G-V2X communications," *Alexandria Engineering Journal*, vol. 70, pp. 553–567, 2023, doi: 10.1016/j.aej.2023.02.044.
- [3] H. Su, L. L. Wu, and Y. Zhang, "Analysis and design of filtering series-fed omni-directional antenna for V2X application," *IEEE Transactions on Antennas and Propagation*, vol. 70, no. 12, pp. 11485–11495, 2022.
- [4] K. A. Alblaihed, A. Abohmra, M. U. Rehman, Q. H. Abbasi, M. A. Imran, and L. Mohjazi, "Wideband series-fed patch antenna array with high gain and low sidelobe: linearly and circularly polarized for 5G V2X applications," *IEEE Open Journal of Antennas and Propagation*, vol. 5, no. 6, pp. 1581–1591, 2024.
- [5] J. Feng, J. Chen, S. Yin, C. Sim, and Z. Zhao, "A tri-polarized antenna with diverse radiation characteristics for 5G and V2X communications," *IEEE Transactions on Vehicular Technology*, vol. 69, no. 9, pp. 10115–10126, 2020.
- [6] A. Kumar, S. Rana, A. Muhan, G. Srivastava, S. Kumar, and K. W. Kim, "A self-decoupled MIMO patch antenna system for V2X communications," *IEEE Access*, pp. 56021–56033, 2025, doi: 10.1109/ACCESS.2025.3554151.
- [7] Z. H. Nafilah, Zulfi, E. Kurniawan, and A. Munir, "Design and implementation of Vivaldi antenna with modified Marchand balun for V2X communications," in *IEEE BlackSeaCom*, 2024, pp. 176–179. doi: 10.1109/BlackSeaCom61746.2024.10646215.
- [8] A. Yacoub, M. Khalifa, and D. N. Aloï, "Wide bandwidth low profile PIFA antenna for vehicular SUB-6 GHz 5G and V2X wireless systems," *Progress In Electromagnetics Research C*, vol. 109, pp. 257–273, 2021, doi: 10.2528/PIERC21010609.
- [9] L. O. N. Zulfi, S. Rahayu, and A. Munir, "A wideband Vivaldi antenna with modified planar Marchand balun for mmWave V2X communications," in *GSMM*, 2024, pp. 139–141. doi: 10.1109/GSMM61775.2024.10553166.
- [10] Y.-B. Kim and H. L. Lee, "Compact planar phased array antenna for extended V2X communication coverage," *Alexandria Engineering Journal*, vol. 94, pp. 226–234, May 2024, doi: 10.1016/j.aej.2024.03.054.
- [11] C. A. D. Prasetyo, M. F. Maulana, S. M. Ahmad, A. F. Faadhilah, and A. Munir, "Experimental investigation of bending impact on radiation characteristics of coating-based flexible multiband antenna," in *Proceedings of the IEEE Asia Pacific Conference on Wireless and Mobile (APWiMob)*, Nov. 2024, pp. 7–12. doi: 10.1109/APWiMob64015.2024.10792956.
- [12] L. Berrich and L. Zenkour, "PIFA antenna for RFID application at 5.8 GHz," *Journal of Engineering and Applied Sciences (ARPN)*, vol. 12, pp. 4565–4569, 2017.
- [13] B. Nikam and B. Patil, "Design and development of multiband PIFA antenna for vehicular LTE/5G and V2X communication," *EURASIP Journal on Wireless Communications and Networking*, pp. 1–15, 2023, doi: 10.1186/s13638-023-02306-8.
- [14] A. Jabber, A. Jassim, and H. Thaher, "Compact reconfigurable PIFA antenna for wireless applications," *TELKOMNIKA Telecommunication, Computing, Electronics and Control*, vol. 18, no. 2, pp. 595–602, 2020, doi: 10.12928/TELKOMNIKA.v18i2.13427.
- [15] L. Berrich and L. Zenkour, "Microstrip dipole antenna for RFID applications at 2.45 GHz," *International Journal of Electrical and Computer Engineering*, vol. 6, no. 6, pp. 2891–2899, 2016, doi: 10.11591/ijece.v6i6.11408.
- [16] R. Vallikannu, M. Vinoth, V. Koushick, and E. A. Mohamed Ali, "A miniaturized defected ground patch antenna for ITS 5G-V2X-C applications," in *International Conference on Computer Communication and Informatics (ICCCI)*, 2022, pp. 1–6. doi: 10.1109/ICCCI54379.2022.
- [17] S. Arianos, G. Dassano, F. Vipiana, and M. Orefice, "Design of multi-frequency compact antennas for automotive communications," *IEEE Transactions on Antennas and Propagation*, vol. 60, no. 12, pp. 5604–5612, Dec. 2012, doi: 10.1109/TAP.2012.2213052.
- [18] Horng-Dean Chen and Yu-Hung Tsao, "Low-profile PIFA array antennas for UHF band RFID tags mountable on metallic objects," *IEEE Transactions on Antennas and Propagation*, vol. 58, no. 4, pp. 1087–1092, Apr. 2010, doi: 10.1109/TAP.2010.2041158.
- [19] Q. Zhang, M. Elahi, and S. Gupta, "A compact wideband V2X reconfigurable fractal antenna with polarization diversity for urban vehicular environments," *IEEE Transactions on Vehicular Technology*, vol. 75, no. 4, pp. 2980–2989, 2026.
- [20] M. A. Mario, M. F. Maulana, B. Syihabuddin, N. Ismail, M. R. Effendi, and A. Munir, "Compact asymmetric-slit aperture coupled square patch antenna for V2X communications," in *2025 7th Global Power, Energy and Communication Conference (GPECOM)*, 2025, pp. 1084–1088. doi: 10.1109/GPECOM65896.2025.11061905.
- [21] A. Jantošová, J. Mergoš, I. Dolnák, and J. Litvik, "A comparative study of the most perspective radio access technologies for vehicular V2X networks," in *ICETA*, 2020, pp. 243–247. doi: 10.1109/ICETA51985.2020.9379171.
- [22] S. M. Ahmad, S. Indriani, T. Yunita, M. N. Arira, J. Zaid, and A. Munir, "Characteristics measurement of wearable embroidered disc-shaped textile array antenna," in *Proceedings of the IEEE International Workshop on Antenna Technology (iWAT)*, Feb. 2025, pp. 1–4. doi: 10.1109/iWAT64079.2025.10931223.

- [23] E. P. Nurani, R. P. Agripamungkas, M. F. Maulana, R. B. Renwarin, and A. Munir, "Characteristic improvement and realization of dome-shaped patch antenna as EMI sensor," in *Proceedings of the IEEE International RF and Microwave Conference (RFM)*, Dec. 2022, pp. 1–4. doi: 10.1109/RFM56185.2022.10064718.
- [24] S. Dey, P. Satheesh, M. S. Keerthi, N. Kunju, and S. Dey, "Novel dual band high gain antenna array using aperture coupled feeding for X-band radar," in *Proceedings of the International Conference on Microwave, Antenna and Communication (MAC)*, Mar. 2023, pp. 1–5. doi: 10.1109/MAC58191.2023.10177128.
- [25] A. Yacoub and D. Aloï, "Low profile PIFA antenna for vehicular 5G and DSRC communication systems," *SAE Technical Papers*, Apr. 2021, doi: 10.4271/2021-01-0150.

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