A Wideband Compact Antenna for Vehicles Communication in ITS Applications

Allam M. Ameen¹, ², *, Mohamed I. Ahmed², Hala Elsadek², and Wagdy R. Anis¹

Abstract—A wideband compact shark-fin antenna operating in a frequency band from 2.86 GHz to 7.68 GHz is presented. The proposed design is realized on a substrate material of “Rogers 4003C” with \(\varepsilon_r = 3.48\), \(\tan \delta = 0.0027\), and substrate thickness 0.81 mm. The antenna is designed to operate at a center frequency of 5 GHz with an operating bandwidth of 4.82 GHz (96.4%). The bandwidth covers the lower band and mid band of 5G at resonant frequencies of 3.5 GHz and 5.8 GHz, respectively. The realized gain of the proposed antenna is 4.1 dBi and 5.35 dBi in the lower band and mid band, respectively. The proposed antenna is designed and simulated. It is also fabricated using photolithography techniques and measured using an R&S vector network analyzer. Good agreement is obtained between the simulated and measured results.

1. INTRODUCTION

High speed wireless communication systems are increasing at a rapid rate in the automotive industry. Since the antenna is one of the important parts of any communication system, it has been rapidly developed to meet the requirements of these systems. The trend to apply the 5G technology is because the 3G and 4G technologies still cannot be used in some applications such as vehicle-to-vehicle (V2V) or vehicle-to-everything (V2X) communication systems. Intelligence transportation system (ITS) is built depending on 5G technology which presents a high reliability, low latency, enhanced data rate, and increased bandwidth [1–4]. This system improves the road safety by avoiding car accidents and reducing traffic jams. Vehicle-to-everything (V2X) can be classified into four categories: vehicle-to-vehicle (V2V), vehicle-to-personal (V2P), vehicle-to-infrastructure (V2I), and vehicle-to-network (V2N) [5–7]. The electrostatic discharges (ESD) are considered in the antenna design because these discharges may have an effect on the communication system through the antenna. Therefore, DC grounding to bypass the ESD should be considered as a mandatory requirement for the vehicular antenna which is built on the rooftop of the vehicle [8, 9]. The antenna placement of the V2V system is studied and discussed [10]. There are many V2V antenna designs that are mounted on the rooftop [11–15]. A microstrip planar and conformal antenna, which operates in the X and Ku bands, is discussed [13]. A shark-fin rooftop multiband antenna for the automotive industry is presented [15]. Another technique that is applied to the V2V antenna design is reconfigurable antennas [16–20]. A novel planar shark-fin reconfigurable antenna based on an electronically switched parasitic (ESP) array radiator, operating at 5.9 GHz, is introduced [16]. A printed wideband pattern reconfigurable antenna using ESP stubs, operating from 1.88 to 2.55 GHz, is also presented [20].

Ultra-wideband (UWB) coplanar antennas have been growing rapidly as a suitable technology for many 5G applications such as ITS, vehicle communications, and location tracking [21–23]. A compact
dual band antenna suitable for 5G applications is discussed in [24, 25]. UWB is mainly used to short-range applications due to the limitations of power spectral density [26]. UWB antenna has several advantages, such as small size, easy fabrication and feed, good immunity against fading effects, and suitable gain, which are needed for 5G applications. A hexagon broadband microstrip antenna loaded with V-shape slots with different sizes and shorting pins, operating from 4.74 GHz to 6.79 GHz, is presented in [22]. A compact coplanar stripline-fed UWB antenna with a staircase-shaped radiating element and a shorted strip is introduced. A high reduction in size is achieved in this design [26].

In this paper, a multiband compact antenna is designed, simulated, and fabricated for a V2V wireless communication system. The proposed antenna operates at a wideband of 2.86–7.68 GHz to cover the lower and mid bands of 5G applications. This structure has a low profile, planar geometry, is easy to fabricate, and has low complexity. It can be used in a shark-fin mobile system.

2. PROPOSED ANTENNA DESIGN

A compact antenna design is presented to cover the low and mid bands of 5G applications. The geometry of the proposed antenna is shown in Fig. 1. The antenna is designed on a substrate of type “Roger 4003C” with \( \varepsilon_r = 3.48 \), loss tangent \( \tan \delta = 0.0027 \), and 0.81 mm thickness. The size of the antenna is \( L_{\text{sub}} = 39.6 \text{ mm} \) and \( W_{\text{sub}} = 28.35 \text{ mm} \). The structure consists of a circular patch slot antenna cut on the top ground. Six parasitic strips are added to the designed antenna, three on the left side and three on the right side. The antenna is fed with a 50 Ohm microstrip feed line placed at the center of the substrate. Table 1 shows the dimensions of the structure in mm. The proposed structure passed through four stages to reach the final design. Fig. 2 shows the four steps that explain the antenna design.

![Figure 1. The geometry of the proposed antenna, (a) complete geometry, and (b) dimensions of the proposed antenna.](image)

| Parameter | Length [mm] | Parameter | Length [mm] |
|-----------|-------------|-----------|-------------|
| \( L_{\text{sub}} \) | 28.35       | \( W_{\text{sub}} \) | 39.6        |
| \( L_{S1} \)  | 9.23        | \( W_{S1} \)  | 2.9         |
| \( L_{S2} \)  | 14.15       | \( W_{S2} \)  | 3.2         |
| \( L_f \)    | 16.83       | \( W_f \)    | 3.3         |
| \( g \)      | 1           | \( W_g \)    | 5.12        |
| \( R \)      | 14.43       | \( d \)      | 7.5         |
design procedures. The first step initiates the design of a coplanar circular slot antenna with a partial stub to connect the feeding ground. In the next step, two strips are added at the center of the circular slot from the left and right. The impedance matching is improved, but the bandwidth is decreased. Then, another two strips are placed at the top of the proposed design. Both impedance matching and bandwidth are improved. In the last step, two strips are placed at the bottom of the proposed design. Fig. 3 shows the change in the return loss ($S_{11}$) for each design step. By tuning the width of the three strips $W_s1, W_s2$, the length of the middle strip $L_s1$, the length of the upper and lower strips $L_s2$, and their position $d$, the bandwidth and return loss of the antenna are changed.

A parametric study is obtained for each dimension individually while the other parameters are constant. The change in the width of the strips affects the bandwidth of the proposed antenna. In Fig. 4, increasing $W_s2$ tends to increase the impedance bandwidth as well as improve the return loss ($S_{11}$). The width $W_s2$ is chosen to be 3.2 mm. Fig. 5 shows how changing the length of $L_s2$ tends to improve the return loss ($S_{11}$) at the high band. However, as the length increases, the bandwidth
Figure 5. A parametric study of the increase and decrease in the length $L_{S2}$.

Figure 6. A parametric study of the increase and decrease in the width $g$.

Figure 7. The simulated radiation pattern of the proposed antenna structure at frequencies of (a) 3.5 GHz, (b) 5.8 GHz, and (c) 7 GHz.
decreases. A tradeoff between improving the return loss and decreasing the bandwidth has occurred. The length $L_{s2}$ is chosen to be 14.15 mm. Fig. 6 illustrates the effect of changing the gap between the feedline and ground $g$, which tends to improve the return loss ($S_{11}$) in the overall band. The width of this gap affects the impedance matching of the proposed antenna and the most suitable dimension is 1 mm. Elaborating results of all parametric studies, it is easy to choose the proper dimensions that achieve the overall bandwidth from 2.86 to 7.68 GHz based on the required specifications and application. Fig. 7 shows the radiation pattern of the proposed antenna at the frequencies 3.5 GHz, 5.8 GHz, and 7 GHz. In Fig. 8, the overall antenna gain for the designed antenna is presented. The designed antenna has a maximum gain of 7.35 dBi at a frequency of 7.3 GHz, while the gain at 3.5 GHz and 5.8 GHz is 4.1 dBi and 5.35 dBi, respectively.

3. RESULTS AND DISCUSSION

The proposed antenna is designed and simulated by the CST software. This structure operates at a wideband of frequency stared from 2.86 GHz to 7.68 GHz (96.4%) to cover the ITS and 5G applications at low and mid bands. It has a return loss below the $-14$ dB at the overall bands of the proposed structure. The antenna is fabricated using the photolithography method and measured using a vector network analyzer (R&S ZVA 67). Fig. 9 shows the fabricated antenna. Good agreement is achieved between the simulated and measured results.

The return loss comparison curves are shown in Fig. 10. Because of the necessary usage of cables during tests and manufacturing, losses may cause tiny variations in the resonant frequency, but generally, the measured and simulated results are similar. Minor jumps in return loss are detected owing to the tester’s poor connection of the cable to the connector during measurement. However, the observed bandwidth of proposed antenna is similar to the simulated one. The gain of the antenna is also measured, and Fig. 11 shows the comparison between measured and simulated results. As shown in Fig. 12, the comparison between simulated and measured radiation patterns is introduced. There are some slight deviations between the measured curve and simulated curve, but the results are generally acceptable. Fig. 13 shows a comparison between the total efficiencies of the proposed design as calculated from CST and HFSS. In CST, the proposed antenna has a total efficiency of 97.3% and 94.6% at 3.5 GHz and 5.8 GHz, respectively. In HFSS, it has a total efficiency of 95.6% and 95.8% at 3.5 GHz and 5.8 GHz, respectively. The comparison between this work and previous works is tabulated in Table 2. Although there are some previous designs that have a higher gain, the proposed antenna is distinguished by being small in size compared to designs in the same frequency bands and having dual bands, not a single band. Moreover, its bandwidth (at $-10$ dB) is up to 96.4%, which is very large compared with previous designs.
**Table 2.** Comparison with previous works.

| Paper  | [1] | [16] | [17] | [22] | [24] | [25] | This Work |
|--------|-----|------|------|------|------|------|-----------|
| Center Frequency [GHz] | 3.5 | 5.8  | 5.9  | 5.8  | 3.5  | 28  | 3.5       |
|         |     |      |      |      | 5    | 39  | 5.8       |
| Single or Dual bands | Single | Single | Single | Single | Dual | Dual | Dual |
| Bandwidth (at -10 dB) [%] | 12.57 | 8.27 | 6.78 | 35.55 | 14.28 | 28 | 11.7 | 10.25 | 96.4 |
| Gain (dBi) | 7 | 6.15 | 5.4  | 4.2  | 2.5  | 5.6 | 4.1 | 9.4 | 4.1 | 5.35 |
| Size (in mm) | 37.4 × 37.4 | 200 × 200 | 37 × 32 | 60 × 60 | 32 × 20 | 6.34 × 7.6 | 39.6 × 28.35 |

- **Figure 10.** The comparison of simulated and measured $S_{11}$ results for single element antenna.
- **Figure 11.** The comparison between simulated and measured overall gain versus frequency.

(a) ![Simulated Measured](image1.png)  (b) ![Simulated Measured](image2.png)
Figure 12. The comparison between simulated and measured radiation pattern $E$-plane at, (a) 3.5 GHz, (b) 5.8 GHz, and (c) 7 GHz.

Figure 13. The total efficiency of the proposed antenna.

4. CONCLUSION

A wideband compact shark-fin antenna operating at a frequency band of 2.86 GHz–7.68 GHz to cover the lower and mid bands of 5G applications has been introduced. The designed antenna achieves a wide bandwidth of 96.4% around the operating center frequency of 5 GHz. Because of its features, such as a low profile, planar geometry, ease of fabrication, and low complexity, it can be used in the shark-fin mobile system. The achieved gain of the proposed antenna is 4.1 dBi and 5.35 dBi in the lower band and mid band, respectively. The antenna is fabricated and measured.

REFERENCES

1. Wang, H. and G. Yang, “Design of 4 × 4 microstrip Quasi-Yagi beam-steering antenna array operation at 3.5 GHz for future 5G vehicle applications,” International Workshop on Antenna Technology: Small Antennas, Innovative Structures, and Applications (iWAT), 331–334, Mar. 2017, doi: 10.1109/iwat.2017.7915393.
2. Arya, A. K., S. J. Kim, and S. Kim, “A dual-band antenna for LTE-R and 5G lower frequency operations,” *Progress In Electromagnetics Research Letters*, Vol. 88, 113–119, 2020.

3. Khalifa, M. O., A. M. Yacoub, and D. N. Alo, “A multiwideband compact antenna design for vehicular sub-6 GHz 5G wireless systems,” *IEEE Transactions on Antennas and Propagation*, Vol. 69, No. 12, 8136–8142, Aug. 2021, doi: 10.1109/TAP.2021.3083770.

4. Arya, A. K., S. J. Kim, S. Park, D.-H. Kim, R. S. Hassan, K. Ko, and S. Kim, “Shark-fin antenna for railway communications in LTE-R, LTE, and lower 5G frequency bands,” *Progress In Electromagnetics Research*, Vol. 167, 83–94, 2020.

5. Liu, A. and Y. Lu, “Low-profile patch antennas with enhanced horizontal omnidirectional gain for DSRC applications,” *IET Microwaves, Antennas & Propagation*, Vol. 12, No. 2, 246–253, 2018, doi: 10.1049/iet-map.2017.0845.

6. Li, C., W. Chen, J. Yu, et al., “V2V radio channel properties at urban intersection and ramp on urban viaduct at 5.9 GHz,” *IET Communications*, Vol. 12, No. 17, 2198–2205, 2018, doi: 10.1049/iet-com.2018.5247.

7. Wevers, K. and M. Lu, “V2X communication for ITS-from IEEE 802.11p towards 5G,” *IEEE 5G Tech Focus*, Vol. 1, No. 2, Jun. 2017.

8. Fujita, K., “MNL-FDTD/SPICE method for fast analysis of short-gap ESD in complex systems,” *IEEE Transactions on Electromagnetic Compatibility*, Vol. 58, No. 3, 709–720, Jun. 2016, doi: 10.1109/temc.2016.2532888.

9. Wang, S., K. M. Mak, H. W. Lai, et al., “Printed circularly polarized wire antennas with DC grounded stub,” *Microwave and Optical Technology Letters*, Vol. 54, No. 12, 2719–2725, 2012, doi: 10.1002/mop.27181.

10. Díez, M. B., P. Plitt, W. Pascher, et al., “Antenna placement and wave propagation for Car-to-Car communication,” *European Microwave Conference (EuMC)*, 207–210, Sept. 7–10, 2015, doi: 10.1109/eu-mc.2015.7345736.

11. Wu, Q., Y. Zhou, and S. Guo, “An L-sleeve L-monopole antenna fitting a shark-fin module for vehicular LTE, WLAN, and car-to-car communications,” *IEEE Transactions on Vehicular Technology*, Vol. 67, No. 8, 7170–7180, Apr. 2018, doi: 10.1109/tvt.2018.2828433.

12. Cerretelli, M., V. Tesi, and G. B. Gentili, “Design of a shape-constrained dual-band polygonal monopole for car roof mounting,” *IEEE Transactions on Vehicular Technology*, Vol. 57, No. 3, 1398–1403, May 2008, doi: 10.1109/tvt.2007.912153.

13. Bhatia, M., M. Dimri, and B. Chauhan, “Rooftop antenna for vehicular application,” *Innovations in Electrical and Electronic Engineering*, 617–625, Singapore, May 2021, doi: 10.1007/978-981-16-0749-3_48.

14. Melli, F., S. Lenzini, M. Cerretelli, et al., “Low profile wideband 3D antenna for roof-top LTE vehicular applications,” *IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC)*, 157–159, Sept. 2019, doi: 10.1109/APWC.2019.8870503.

15. Ghafari, E., A. Fuchs, D. Eblenkamp, et al., “A vehicular rooftop, shark-fin, multiband antenna for the GPS/LTE/cellular/DSRC systems,” *IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC)*, 237–240, Aug. 2014, doi: 10.1109/apwc.2014.6905546.

16. Rongas, D., A. Paraskevopoulos, L. Marantis, and A. G. Kanatas, “An integrated shark-fin reconfigurable antenna for V2X communications,” *Progress In Electromagnetics Research C*, Vol. 100, 1–16, 2020.

17. Kim, S., D. Kang, and J. Choi, “Beam reconfigurable antenna using switchable parasitic elements for V2V applications,” *International Symposium on Antennas and Propagation (ISAP)*, 1–2, Oct. 2017, doi: 10.1109/ISANP.2017.8229006.

18. Kowalewski, J., J. Mayer, T. mahler, et al., “A compact pattern reconfigurable antenna utilizing multiple monopoles,” *2016 International Workshop on Antenna Technology (iWAT)*, 1–4, Mar. 2016, doi: 10.1109/iwat.2016.7434783.
19. Kowalewski, J., T. Mahler, J. Mayer, et al., “A miniaturized pattern reconfigurable antenna for automotive applications,” *10th European Conference on Antennas and Propagation (EuCAP)*, 1–4, Apr. 2016, doi: 10.1109/EuCAP.2016.7481207.

20. Jose, M. C., R. Chithra Devi, B. S. Sreeja, et al., “A novel wideband pattern reconfigurable antenna using switchable parasitic stubs,” *Microwave and Optical Technology Letters*, Vol. 61, No. 4, 1090–1096, Apr. 2019, doi: 10.1002/mop.31698.

21. Wei, K., Z. Zhang, and Z. Feng, “Design of a coplanar integrated microstrip antenna for GPS/ITS applications,” *IEEE Antennas and Wireless Propagation Letters*, Vol. 10, 458–461, May 2011, doi: 10.1109/LAWP.2011.2152361.

22. Hao, H., J. Li, D. Huang, et al., “Design of hexagon microstrip antenna for vehicle-to-vehicle communication,” *The Journal of China Universities of Posts and Telecommunications*, Vol. 23, No. 4, 69–76, Aug. 2016, doi: 10.1016/S1005-8885(16)60047-X.

23. Sai, M. Y., S. Kavya, S. R. Bhimavarapu, et al., “CPW fed microstrip patch antenna for dedicated short-range communication,” *Wireless Personal Communications*, 1–15, Sept. 2021, doi: 10.1007/s11277-021-09114-7.

24. Zhang, Y., H. Zheng, B. Gao, C. Tang, R. Liu, and M. Wang, “A compact dual-band antenna for 5G application,” *Cross Strait Quad-Regional Radio Science and Wireless Technology Conference (CSQRWC)*, 1–2, Jul. 2019.

25. Babbar, P., S. Mishra, A. Rajawat, and S. Saxena, “Design of an L-shaped dual band patch antenna for 5G applications,” *2021 8th International Conference on Signal Processing and Integrated Networks*, 1108–1113, SPIN, Aug. 2021.

26. Roshna, T. K., U. Deepak, V. R. Sajitha, et al., “Coplanar stripline-fed compact UWB antenna,” *Electronics Letters*, Vol. 50, No. 17, 1181–1182, Aug. 2014, doi: 10.1049/el.2014.1884.