Design and Analysis of a Circularly polarized flexible, compact and transparent antenna for Vehicular Communication Applications

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Abstract-A Compact, flexible, and circularly polarized transparent monopole antenna is proposed for vehicular communication applications by IEEE 802.1p standard. Canopy mesh is used as a conductive layer and the PDMS substrate is used as a substrate with dielectric constant $\varepsilon_r = 2.66$ and loss tangent $\tan \delta = 0.023$. The overall dimension of the proposed antenna is $20 \times 20 \times 1 \text{ mm}^3$. The rectangular patch with a T-shape slot with a truncated corner and partial ground provide resonant frequency at 5.85 GHz with a reflection coefficient ($S_{11}$) bandwidth of 5.2 - 6.86 GHz (1.66 GHz) and axial ratio (dB) bandwidth of 5.7 GHz-6.14 GHz (404 MHz).

Keywords: PDMS (Polydimethylsiloxane), Transparent, compact, Vehicular communication

1. Introduction

Nowadays, Vehicular communication plays an important role due to the concept of smart vehicles and IoT (Internet of Things) [1]. In vehicular communication electronic systems, the antenna is the main element to sense, analyse, and integrate using the IEEE 802.1p standard for communication. The vehicular networks can communicate from vehicle to vehicle, vehicle to everything, and vehicle to infrastructure which is broadly classified into inter and intra vehicular communications [2].

To satisfy the increased demand and requirements for compact, flexible, and transparent antennas on vehicle platforms without disturbing the vehicle mechanism, various antenna structures are proposed in [3-5]. Various flexible and transparent substrates like PET, PDMS (Polydimethylsiloxane), etc. [6], and conductive portions like AgHT-8, Indium Tin Oxide (ITO), etc. In addition, different fabrication methods like Inkjet printing, screen printing, etc. [7] for integrating conductive elements into the substrate.

In this paper, a flexible, compact, and transparent antenna is proposed using a PDMS substrate with dielectric constant $\varepsilon_r = 2.66$ and loss tangent $0.023$. The proposed monopole antenna has a rectangular patch with a T-shape slot and a truncated corner. The partial ground is used to operate the antenna with 2.94 dB gain at 5.85 GHz frequency with $S_{11}$ bandwidth of 1.66 GHz and Axial Ratio bandwidth of 404 MHz. The design and simulation of the proposed antenna have been performed in an Ansys HFSS environment. The proposed antenna is fabricated using Canopy Mesh fabric as a conductive element with 0.1ohm/sq. resistivity and PDMS substrate with dimensions $20 \times 20 \times 1 \text{ mm}^3$ which is transparent, flexible, and compact that is opted for a vehicular communication platform.

2. Antenna Layout

The proposed flexible and compact antenna with dimensions is shown in Figure 1. PDMS substrate has been used as a substrate with dielectric constant $\varepsilon_r = 2.66$ and loss tangent $\tan \delta = 0.023$. The rectangular patch with a T-shaped slot and partial ground provides resonance at 5.85 GHz. The corners of the patch are truncated that provide circular polarization at the resonant frequency. The Evolution of the proposed antenna is presented in Figure 2. The reflection coefficient at each design step in the evolution process is shown in Figure 3.
3. Materials and fabrication

The PDMS substrate has been prepared by mixing Sylgard 184 silicone elastomer with a curing agent shown in Figure 4 (a) with 10:1 proportion. The mixer is stirred and using a desiccator to eliminate bubbles and it is poured into a 1mm height rectangular slab thereafter heated up to 100°C to prepare as a layer which is having transparent nature. The layer is adjusted to get the dimensions $20 \times 20 \times 1 \text{ mm}^3$. The Canopy Mesh Fabric has been used as a conductive part of the antenna, which has resistivity 0.1 ohm/sq., 1mm hole gap, and transparent nature as shown in Figure 4 (b). The mess is formed with Tin coated copper wire which can be easily cut and adjusted according to the antenna structure as shown in Figure 4 (c).
4. Simulation Results and Discussions

The proposed antenna is simulated using the Ansys HFSS simulation environment. The antenna resonates at 5.85 GHz frequency with $S_{11}$ (dB) bandwidth of 1.66 GHz presented in 5 (a). The circular polarization due to corner truncation at the radiating patch is represented using the axial ratio (dB) as shown in Figure 5(b) with an axial ratio (dB) bandwidth of 404 MHz.

The simulated electric field distribution at 5.85 GHz frequency is given in Figure 6 (a), it is observed that maximum radiation occurs at the edges of the patch. Figure 6 (b), showing the radiation pattern distribution imposed on antenna structure which has the Peak Gain of 2.94 dB with dipole like radiation pattern.
The proposed antenna is compared with existing vehicular communication antenna literature in Table 1 below.

Table 1: Comparison with Literature

| Ref.  | Size (L × W × t) (mm³) | Substrate       | S_{11} (dB) Band width | Axial Ratio (dB) Bandwidth | Gain (dB)/ Transparent |
|-------|------------------------|-----------------|------------------------|---------------------------|------------------------|
| [8]   | 60×10×0.375            | Sapphire        | 2.19-2.58 GHz/390 MHz  | NR                        | NR/yes                |
| [9]   | 58×78×1.11             | PET             | 3.89-5.97 GHz/2.08 GHz | NR                        | 5.1 /yes              |
| [10]  | 25×25×1.1              | Glass           | 2-6 GHz/4 GHz          | NR                        | -4.8 /yes             |
| Proposed | 20×20×1               | PDMS            | 5.2-6.86 GHz/1.66 GHz  | 5.7-6.14 GHz/404 MHz      | 2.94/Yes              |

5. Conclusion

In this work, a compact, flexible, and transparent monopole antenna was designed and fabricated. The PDMS with dielectric constant 2.66 and loss tangent 0.023 and Canopy mesh fabric with resistivity 0.1 ohm /sq., dimensions 20 × 20 × 1 mm³ as substrate and conductive portions. The design and simulation are performed using the Ansys HFSS tool and gives a resonance at 5.85 GHz and axial ratio bandwidth with a gain of 2.94 dB. The transparent nature, compact, and flexibility make it suitable for vehicular communication applications.
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References:
[1]. Green, R.B., Guzman, M., Izyumskaya, N., Ullah, B., Hia, S., Pitchford, J., Timsina, R., Avrutin, V., Ozgur, U., Morkoc, H. and Dhar, N., 2019. Optically transparent antennas and filters: A smart city concept to alleviate infrastructure and network capacity challenges. IEEE Antennas and Propagation Magazine, 61(3), pp.37-47.
[2]. Rahim, A., Malik, P.K. and Ponnapalli, V.S., 2020. State of the Art: A Review on Vehicular Communications, Impact of 5G, Fractal Antennas for Future Communication. In Proceedings of First International Conference on Computing, Communications, and Cyber-Security (IC4S 2019) (pp. 3-15). Springer, Singapore.
[3]. Trujillo-Flores, J.I., Torrealba-Meléndez, R., Muñoz-Pacheco, J.M., Vásquez-Agustín, M.A., Tamariz-Flores, E.I., Colín-Beltrán, E. and López-López, M., 2020. CPW-Fed Transparent Antenna for Vehicle Communications. Applied Sciences, 10(17), p.6001.
[4]. 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, pp.1-10.
[5]. Madhav, B.T.P. and Anilkumar, T., 2018. Design and study of multiband planar wheel-like fractal antenna for vehicular communication applications. Microwave and Optical Technology Letters, 60(8), pp.1985-1993.
[6]. Goliya, Y., Rivadeneyra, A., Salmeron, J.F., Albrecht, A., Mock, J., Haider, M., Russer, J., Cruz, B., Eschlwech, P., Biebl, E. and Becherer, M., 2019. Next Generation Antennas Based on Screen-Printed and Transparent Silver Nanowire Films. Advanced Optical Materials, 7(21), p.1900995.
[7]. Lee, S.Y., Choo, M., Jung, S. and Hong, W., 2018. Optically transparent nano-patterned antennas: a review and future directions. Applied Sciences, 8(6), p.901.
[8]. Green, R.B., Toporkov, M., Ullah, M.D.B., Avrutin, V., Ozgur, U., Morkoc, H. and Topsakal, E., 2017. An alternative material for transparent antennas for commercial and medical applications. Microwave and Optical Technology Letters, 59(4), pp.773-777.
[9]. Kashanianfard, M. and Sarabandi, K., 2017. Vehicular optically transparent UHF antenna for terrestrial communication. IEEE Transactions on Antennas and Propagation, 65(8), pp.3942-3949.
[10]. Hakimi, S., Rahim, S.K.A., Abedian, M., Noghabaei, S.M. and Khalily, M., 2014. CPW-fed transparent antenna for extended ultrawideband applications. IEEE Antennas and Wireless Propagation Letters, 13, pp.1251-1254.