CPW-fed conformal ESP antenna for vehicular applications

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Abstract. In this work, a new design of a monopole conformal elliptical-shaped patch (ESP) antenna is proposed for vehicular application. The antenna measures 40×60×0.1mm3, designed on the polyimide substrate material. Coplanar Waveguide (CPW) is considered to enhance the bandwidth. The antenna resonates at 4.26GHz, 6.61GHz frequencies, with a bandwidth of 4360MHz (3.35GHz-7.71GHz). The 3D-gains are 4dBi, 4.2dBi for the two resonant frequencies. The radiation characteristics are observed semi-omnidirectional and directional. Bending analysis is also considered to check its compatibility on the vehicular surface. The antenna can be widely used in the field of Vehicular application for its advantages of simple structure, flexibility, and low profile.

Keywords: Conformal antenna, Coplanar Waveguide (CPW), vehicle-to-vehicle (V2V) communication, Vehicular communication, Wideband.

1. Introduction
The advancements in antenna designing spread to new industries like automobile engineering to meet the growing requirements and competition. The navigation systems in the vehicles not only give information about the traffic, but it also finds the shortest route to the drivers [1]. Currently, vehicle-to-vehicle (V2V) communication is the most attractive field for researchers to design effective and efficient vehicular communication systems. Antennas play an important role in the V2V communication systems. In modern vehicles, more antennas are placed inside and on the surface of the vehicles for different communication applications [2]. The design considerations of the antennas are very important to reduce the usage of the number of antennas. A single antenna design used for multiple frequencies is the attractive one. The conventional antennas and planar antennas are not suitable to integrate on the surface of vehicles. Conformal antennas are suitable antennas to integrate on the vehicles.

The development of flexible technology requires research efforts on the compatibility of flexible electronics, components, and materials. A portable communication system needs high data rates on one hand and compactness, conformity, and multiband characteristics on the other [3], [4]. Different substrate materials are used to design antennas with good performance and flexibility [5], [6]. The flexible antenna features a lightweight, compact. Moreover, these antennas can be easily fit for conformal surfaces. Apart from the structural complexity, conformal microstrip antennas have the
drawback of low efficiency and narrow bandwidth [7]. Therefore, adopting a bandwidth enhancement and miniaturization techniques without degrading the antenna performance is the main focus in flexible antenna design. Dielectric resonator antenna is proposed [8] by using a parasitic patch to enhance the bandwidth of the antenna. In [9], anisotropic impedance surface (AIS) coatings are used to enhance the bandwidth of the proposed monopole antenna. A transparent CPW-fed dual-band antenna [10] is proposed for active RFID tags. Flexible antennas with slots have good impedance bandwidth. A CPW-fed monopole dual-band antenna [11] is proposed, U-shaped slots are used to enhance the bandwidth. Polyimide-based flexible antennas [12], [13] are proposed for conformal applications.

In this paper, A CPW-fed conformal antenna is proposed for vehicular applications. This antenna can be used in vehicles, and the antenna is designed as a logo itself. The polyimide substrate material is considered to achieve flexibility in antenna. This antenna is placed in such a way that it is less disturbing to the human eye compared to the trunk-mount or roof-mount antenna. Bending analysis is considered to check its compatibility on the vehicular surface. It is fed by CPW to improve impedance matching and enhance bandwidth.

2. Antenna Design

Figure 1 shows the geometry of the proposed monopole elliptic shaped patch (ESP) antenna. The ESP antenna is designed on a 0.1 mm thick polyimide substrate material with a permittivity ($\varepsilon_r$) of 3.5. To comply with flexible technology, the substrate must be highly flexible, robust, and resistant to bending and twisting. The choice of polyimide as the antenna substrate is due to its excellent chemical and physical properties.

![Figure 1. The geometry of the monopole ESP antenna.](image)

As shown in figure 1, the length and width of the substrate are denoted as $L_S$ and $W_S$. Three elliptical-shaped patches (E1, E1, E3) are arranged with proper positioning to optimize the desired band of frequencies. The semi-major axis and semi-minor axis of ellipse1 is denoted as $E1_w$, $E1_l$ respectively. The ground plane on both sides of the feed line with width $W_F$ is $W_G \times L_G$. This is a typical CPW feed design with symmetrical ground planes on both sides. Elliptical shaped slots are considered on the patch in order to make the antenna suitable for the vehicular logo structures. The ESP antenna is designed and optimized using CST Microwave Studio® [17]. The optimized design parameters are shown in table 1.

$$f_{res1,2} = \frac{15}{\pi c_e E1,2_w} \sqrt{\frac{Q_m}{\varepsilon_r}}$$

(1)

Where, $Q_m$ is the Mathieu function and $c_e$ is the eccentricity of the ellipses.
\[ q_m = -0.22 - 0.728 c_{e1,2} + 1.308 c_{e1,2}^2 + \frac{0.341}{1 - c_{e1,2}} \]  \tag{2}

\[ c_{e1,2} = \sqrt{1 - \left( \frac{E_1,2_L}{E_1,2_N} \right)^2} \]  \tag{2}

The first and second resonant frequencies of the proposed ESP antenna are obtained by substituting the equations (2), (3) in the equation (1) [14], [15], [16].

| Table 1. Design parameters of the monopole ESP antenna. |
| Parameter | Value(mm) | Parameter | Value(mm) |
|-----------|-----------|-----------|-----------|
| \( W_S \) | 60        | \( E_1L \) | 13        |
| \( L_S \) | 40        | \( E_1W \) | 22        |
| \( W_G \) | 28.2      | \( E_2L \) | 7         |
| \( L_G \) | 10        | \( E_2W \) | 14        |
| \( W_F \) | 2         | \( E_3L \) | 11        |
| \( L_F \) | 12.8      | \( E_3W \) | 5.5       |

3. Results and discussions

The reflection coefficient (\( S_{11} \)) response of the monopole ESP antenna is shown in figure 2. The lower frequency is observed at 3.35GHz, and upper frequency is observed at 7.71GHz for the bandwidth of 4360MHz (3.35-7.71GHz). The resonant frequencies are observed at 4.26GHz, 6.61GHz, with an \( S_{11} \) of -15.3dB, -24.2dB, respectively.

![Figure 2. S11 characteristics of the monopole ESP antenna.](image)
Figure 3. Gain plots of monopole ESP antenna at (a) 4.26 GHz, (b) 6.61GHz frequencies.

The 3D-gain plots of the conformal monopole ESP antenna are shown in figure 3. The maximum gain of 4.2dBi is observed at 6.61GHz frequency. The gain is observed 4dBi for 4.26GHz frequency.

Figure 4. The surface current distribution of conformal monopole ESP antenna at (a) 4.26 GHz, (b) 6.61GHz frequencies.
The surface currents of the conformal monopole ESP antenna at each operating frequencies are shown in figure 4. A surface current distribution of 79.1 A/m is observed at 4.26GHz frequency. It is observed that for the first resonant frequency, the maximum surface current intensity is focused on the outer edges of the elliptical patch. The second resonant frequency surface currents (99.3A/m) are intensified at the inner edge of the elliptical patches.

As shown in figure 5(a) the E-field and H-field radiation patterns are observed as semi-omnidirectional. The angular width is 81.7, and the main lobe direction is 197deg for E-Field, and for H-field, the angular width is 97.5deg, and the main lobe direction is 173deg.

Figure 5(b) shows the E-Field and H-field radiation patterns of 6.6GHz frequency, and it is observed as bi-directional and semi-omnidirectional. The main lobe direction is 207deg with an angular width of 57.2deg for E-field, and for H-field, the angular width is 211.3deg, and the main lobe direction is 235deg.

![Figure 5](image-url)

**Figure 5.** The surface current distribution of conformal monopole ESP antenna at (a) 4.26 GHz, (b) 6.61GHz frequencies.
4. Bending analysis
The conformal monopole ESP antenna is designed for vehicular applications. As shown in figure 6, the antenna is mounted on a car, which conforms to the surface of the car and doesn't need extra space. So, the antenna is characterized in a bent position to check the antenna performance.

![Figure 6](image)

**Figure 6.** The geometry of the (a) conformal monopole ESP antenna, (b) conformal monopole ESP antenna mounted on car.

The $S_{11}$ response of the conformal monopole ESP antenna is shown in figure 7. The impedance bandwidth of 4280MHz is observed for the resonate bands. It is observed that the performance of the antenna mounted on the car will not affect much. The resonant frequencies are slightly shifted, and the bandwidths are well maintained. The conformal antenna resonates at 4.2GHz, 6.88GHz frequencies with -15.5 dB, -18.2dB reflection coefficients, respectively.

The 3D-gain plots of the conformal monopole ESP antenna are shown in figure 8. The maximum gain of 4.37dBi is observed at 6.88GHz frequency. The gain is observed low 3.51dBi at 4.2GHz frequency.

As shown in figure 9(a) the E-field and H-field radiation patterns are observed as semi-omnidirectional. The main lobe direction is 208deg with an angular width of 117.4deg for E-plane, and for H-plane, the angular width is 92.2deg, and the main lobe direction is 173deg.
Figure 7. S11 of conformal monopole ESP antenna mounted on the car.

Figure 8. Gain plots of conformal monopole ESP antenna at (a) 4.2GHz, (b) 6.88GHz frequencies.

Figure 9(b) shows the E-field and H-field radiation patterns of 6.88GHz frequency, and it is observed as directional and semi-omnidirectional patterns. The angular width is 53.94deg, and the
main lobe direction is 193 deg for E-field, and for H-field, the angular width is 160 deg, and the main lobe direction is 184 deg.

![E-field and H-field radiation patterns](image)

**Figure 9.** E-field and H-field radiation patterns of conformal monopole ESP antenna at (a) 4.2 GHz, (b) 6.88 GHz frequencies.

5. Conclusion

A conformal monopole ESP antenna is proposed for vehicular application. The size of the proposed design is 60×40×0.1 mm³. It is lightweight and flexible. The characteristics of ESP antennas have been investigated for planar and bent configurations. The proposed conformal monopole ESP antenna resonates at 4.26 GHz, 6.61 GHz frequencies with a bandwidth of 4360 MHz (3.35 GHz - 7.71 GHz). The simulated results showed the gain of 4 dBi, 4.2 dBi for respective frequencies. The proposed antenna achieves semi-omnidirectional, directional patterns. Bending analysis is done by placing an antenna on a car, and the performance of the antenna will not deviate. The simulated results are presented, show the usefulness of proposed antenna structure in Electronic Toll Collection (ETC), Wi-Max, and Vehicle-to-Vehicle (V2V) communication applications in vehicles.
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