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Investigation of Curved Patch Antenna Performance in Automotive Environments

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Abstract
The Suzuki automobile logo is used as the model for the antenna design in this instance. One of the most crucial requirements for an antenna designer is that they must be adaptable enough to create car antennas without compromising the vehicle's functioning or appearance. The ideal antenna locations and radiation patterns to ensure adequate reception are now the questions that need to be answered. This paper employs an antenna that synthesis methodology to develop Car-to-Car (C2C) communication in order to detect the obstacles in front and back of the car. This paper makes it possible to optimize antenna radiation patterns according to vehicle-specific constraints. Designing an antenna and presenting it in the car logo systems with enough frequency ranges and volume-related channel knowledge—which can be acquired, for example, through simulations of the fundamental principle behind it. In this paper, here is an attempt to incorporate an antenna into a vehicle's emblem to ensure the enhancement of the drivers' comfort and safety. While taking this objective into account it compares location-specific design constraints.
Keywords: *Car-to-Car (C2C) communication; Suzuki automobile logo; Vehicle functionality.*

1. Introduction
One of the main causes of traffic accidents in India is rear-end collisions. According to figures released by the Ministry of Road Transport and Highways, rear-end incidents claimed the lives of 22,446 people in 2017, 25,801 in 2018, and 32907 in 2023. The task of designing antenna for vehicle system is never easy. A key component of the contemporary vehicle communication system is intelligent transportation (ITS). This infrastructure for vehicle – to – vehicular communication is the primary focus of this project to detect the obstacle. In the field of automobile electronics, technological equipment has been introduced. This represents a semi-transparent antenna design inspired by car logos, utilizing a coplanar waveguide (CPW) feed. The antenna operates over a UWB frequency range and is designed to be integrated into the vehicle's logo maintaining aesthetic appeal while providing necessary communication functionalities. [1-2]

1.1.Objective and Problem Definition
The objective of this project is to design a semi-transparent antenna inspired by car logos, utilizing a coplanar waveguide (CPW) feed. The antenna operates over an ultra-wideband (UWB) frequency range, offering reliable communication for intelligent transportation systems (ITS). The design ensures that the antenna blends aesthetically with the vehicle's logo while providing robust communication functionalities.

1.2.Literature Review and Related Works
[1]. This paper presents a semi-transparent antenna design inspired by car logos, utilizing a coplanar waveguide (CPW) feed. The antenna operates over a UWB frequency range and is designed to be integrated into the vehicle's logo, maintaining aesthetic appeal while providing necessary communication functionalities. [2]. This paper introduces a CPW-fed wideband antenna featuring a modified ground plane tailored for vehicular use. The authors demonstrate that altering the ground structure

significantly enhances bandwidth and gain, making the antenna more effective for obstacle detection and V2V communication. [3]. The authors present a compact UWB MIMO antenna designed for vehicular radar applications, offering improved isolation between ports. By reducing mutual coupling, the antenna achieves better signal clarity and more accurate obstacle detection.[4] This work proposes a miniaturized car logo-inspired antenna specifically for automotive radar applications. The antenna offers compact dimensions while retaining wideband capabilities, making it ideal for seamless integration into vehicle logos. The design ensures consistent performance across various incident angles, which is essential for effective obstacle detection. [5]. This discusses a MIMO antenna system designed for UWB applications, featuring notched bands to mitigate interference from existing narrowband services.[6] This paper introduces a dual-band MIMO antenna optimized for connected vehicles and obstacle detection. The authors implement decoupling structures to enhance isolation, thereby minimizing interference and improving communication reliability. The antenna demonstrates strong performance in V2V and V2X communication, making it well-suited for modern vehicular networks.[7] It introduces a compact four port MIMO antenna designed for automotive communication systems. The antenna is designed to operate over multiple frequency bands relevant to vehicular communications, providing reliable performance while occupying minimal space.[8] The authors present a wideband CPW-fed antenna with enhanced gain and radiation efficiency for vehicular applications. The design achieves stable impedance matching and low return loss over a broad frequency range, ensuring efficient signal transmission. This makes the antenna suitable for automotive radar and wireless communication systems used in obstacle detection.[9] It provides an overview of antenna requirements and designs for autonomous and connected vehicles. The insights offered are crucial for developing antennas that meet the demands of modern vehicular communication systems.[10]. The study presents a quad-port UWB MIMO antenna designed for body-worn applications, ensuring flexibility and conformability. The antenna offers ultra-wideband (UWB) performance, making it suitable for high-data-rate wireless communications. The research highlights its potential applications in biomedical telemetry, military communication, and IoT-based wearable systems. [11]. This study presents an ultra – compact two – port MIMO antenna designed for ultra-wideband (UWB) applications, featuring dual band-notched characteristics to mitigate interference from narrowband systems. The antenna operates over a frequency range of 3.1 – 10.6GHz. [12]. This focuses on the design of a quad port MIMO antenna with dual – band elimination features tailored for UWB applications. The design incorporates modified ground structures and resonators to achieve high isolation between ports and desired band-notch characteristics [13]. The method to enhance isolation in MIMO antennas by employing an Electromagnetic Band Gap (EBG) structure and metal line strips. The techniques discussed can be applied to vehicular antenna designs to ensure high isolation between multiple antenna elements, thereby enhancing overall system performance [14]. This study explores the reduction of mutual coupling in E-shaped MIMO antennas using a matrix of C-shaped resonators. The findings are pertinent to the design of vehicular antennas, where maintaining high isolation between closely spaced elements is essential for reliable operation [15]. The study focuses on a compact monopole antenna designed to fit into a shark-fin module for vehicular applications. The antenna supports LTE, WLAN, and vehicle-to-vehicle (V2V) communications, improving connectivity and smart vehicle networks. The design is optimized for low-profile integration, making it suitable for modern vehicles without affecting aerodynamics. [3]

1.3.Significance and Contribution

The research highlights its role in improving vehicle communication systems for autonomous driving and intelligent transport networks. This paper indulges new features that satisfy the car's extra infotainment and security needs. Ensuring the driver's comfort and safety is the goal of modern services. For reliable operation, smart cars rely on a number of currently available wireless services, including GPS, GSM,

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Bluetooth, WLAN, and LTE. We have an enhanced technology concept based on obstacle detection in our suggested solution. However, as the number of services in the vehicle increases, so does the number of antennae. In order to compensate for ground losses, the automobile antenna should be low-profile, take up minimal room within the car, and be positioned far from the ground plane. [5]

2. Method

Additionally, the location of the antenna shouldn't change how the car looks. This calls for the creation of a multipurpose antenna. To ft the vehicle's aerial configuration, the low-profile antenna can be installed within the shark-fin module. Additionally, the prototype can be installed in the bumper, trunk, chassis, and side mirror cavities. Researchers are paying close attention to multiband/broadband antennas for automotive applications. However, we are here to track the obstructions in front and behind the car by positioning the antennas for the car logo in front and back. This has no bearing on the car's overall design or appearance. Rather, this also makes it much easier for the driver to anticipate the challenges before he even gets to the location. [6-7]

3. Implementation

3.1.Computer Simulation Technology (CST) Tool

The modelling process is made simpler by the software's graphical user interface (GUI). Complex geometries, simulations, and result visualization are all simple for users to accomplish [1]. Advanced Post-Processing Tools: CST has strong post-processing features that let users examine simulation results using a range of visualization choices, such as S-parameters, far-field patterns, and 2D and 3D field plots [2]. Integration with Other Tools: For improved data analysis and simulation workflows, CST can integrate with other software programs (like MATLAB). It has Features for the program which has optimization algorithms that let users improve designs according to particular performance standards, including maximizing gain or decreasing return loss [3]. This paper illustrates how the antenna shape for the Suzuki automobile logo is implemented, where a standard Suzuki "S" form was used in its design. The patch was designed using materials such as 'FR-4 lossy' – Substrate; 'Copper annealed' – Feed; 'Copper annealed' – Ground. Following simulations, the outcomes are being reported. [4]

3.2. Antenna Design

This paper attempts with the antenna design of frequency range with 2 - 6GHz. This frequency range gives enhanced bandwidth and data transmission capacity. Gives a better signal quality Suzuki car has an S-shaped, we are attempting to install this particular antenna design on both the front and rear sides of the vehicle. To compensate for ground losses, the autonomously designed antenna needs to be situated far from the ground, have a low profile, and take up little room in the vehicle. This means the antenna should add to the vehicle's appearance rather than detract from its inherent appeal. This prototype is primarily intended to be placed within the vehicle's branding. We are attempting to incorporate the same elements into the SUZUKI CAR as the Nissan automotive logo already uses this concept. Ultra-Wideband (UWB) technology is widely employed in automated antenna platforms for a variety of applications. To enhance the performance of C2C communication, both the transmitter and the receiver must have numerous antenna systems operating. The antenna is designed with a CPW – fed rectangular patch monopole radiator (evolution 1) and a modified ground plane that covers a wide bandwidth range. The rectangular patch is then evolved into a shape of a basic "S" alphabetic shape (evolution 2), the patch width size is then reduced according to the design of Suzuki logo shape. Evolution 3 defines with the abrupt design to achieve the desired shape of SUZUKI automobile logo. Fig 1 depicts the final evolution of the patch antenna designed. Figure2. illustrates the Suzuki-logo-shaped patch antenna. The antenna's dimensions are selected to resonate within the desired 2 - 6 GHz frequency range, ensuring minimal insertion loss and a wide operational bandwidth. This paper focus on high – efficiency designs while still maintaining a visually appealing logo-inspired structure. It improves feeding techniques, such as proximity-coupled feeding or hybrid approaches, can achieve better isolation and performance. The design can be generalized or customized for a wide range of automotive

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applications and manufactures.

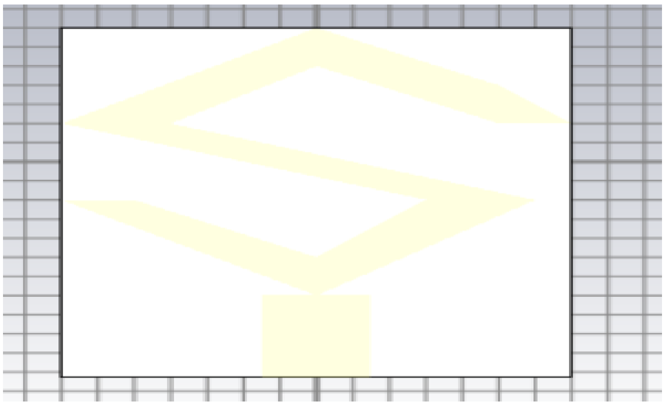

Figure 1 Evolution 1 – Rectangular Patch Antenna

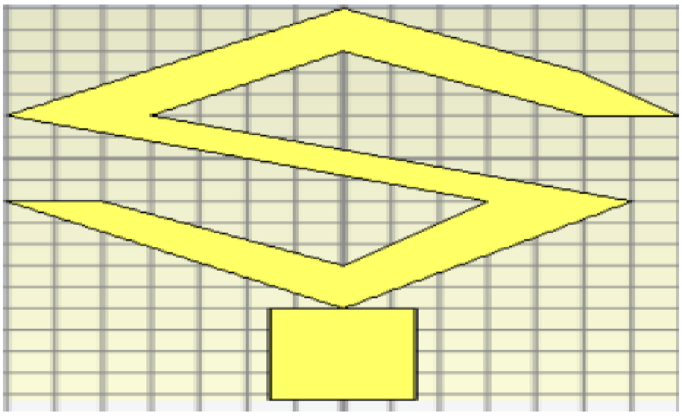

Figure 2 Evolution 2 – Suzuki Shape Feed

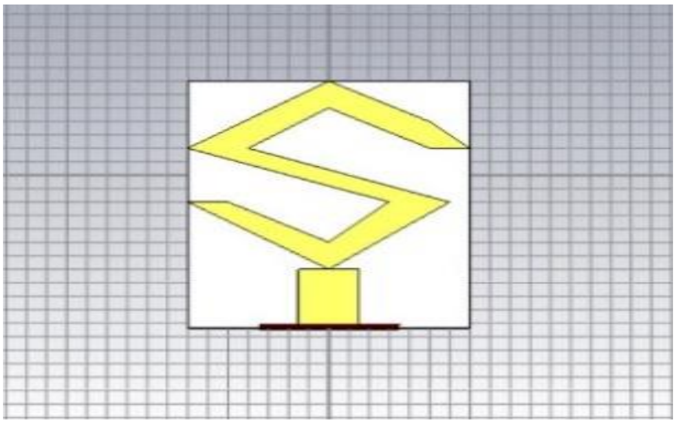

Figure 3 Design of the Suzuki Car Logo Antenna

4. Design Specifications

The finite ground coplanar waveguide feed is provided in the intended antenna design. A coplanar waveguide feed (CPW) has two ground planes on either side and a conductor strip in the middle. Because of its low dispersion, broadband performance, and simplicity of usage, CPW feed is utilized for antenna feeding. The frequency ranges for this fundamental alphabet of "S" shaped antenna is 3.0-4.0 GHz. Point 1 (X axis = 3.169GHz; Y axis = 0.039db) and Point 2 (X axis = 3.473GHz; Y axis = 0.009db) are the two points in the S-Parameter Frequency range. The power results fall within the frequency range of 3-16-3.4 GHz. Between 3 and 4 GHz, the VSWR rises. Additionally, the basic "S" letter shape antenna design is being reduced in this way by decreasing its own size dimensions. As a result, their frequency ranges differ in the S-Parameter, Power, and VSWR ranges between 2-6 GHz. Point 1 (2.1951 – -21.965)) and Point 2 (6.1852GHz to -33.632) dB) are the two points in the S-parameter frequency range. Absorption of power at frequencies between 2 and 3 GHz. VSWR increases between 2 and 3 GHz. We are going to construct an antenna that features an automobile logo in this proposed implementation. In order to continue designing the prototype antenna, we are going to employ the transparent soda lime glass substrate. [8]

Table 1 Experimental Input Parameters for Antenna Patch

Components	Materials Used
Substrate	FR4 – Lossy
Ground	Copper annealed
Patch and Feed	Copper annealed

5. Results and Discussion

5.1. Results

The CST simulations were conducted to analyse the performance of the proposed antenna. [9]

- **Time Signal:** The time-domain response of the antenna reveals the stability of the transmitted and received signals. The results demonstrate a rapid settling of the waveform, with minimal oscillations and interference. This indicates that the antenna design has low dispersion, which is crucial for applications requiring accurate and efficient signal transmission. The observed behaviour validates the effectiveness of the finite ground

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coplanar waveguide (CPW) feed structure in reducing signal distortion. Fig[1]

- Voltage Standing Wave Ratio (VSWR): The VSWR plot highlights the performance of the antenna across the frequency range of interest between (2.1951 – 6.1852GHz) and ((-21.965) to (-33.632) dB). The curve consistently stays below the threshold of 2 within the operating range, indicating efficient impedance matching and low reflection of power. This ensures that the maximum input power is transmitted without significant losses, making the design highly suitable for obstacle detection in vehicular environments. Fig[2] [10]
- **Radiation Pattern:** The 3D radiation pattern provides insight into the directional characteristics of the antenna. The symmetrical and omnidirectional nature of the pattern ensures uniform radiation in both forward and backward directions, critical for detecting obstacles from multiple angles. The results confirm that the proposed antenna design effectively radiates in a manner that covers the required vehicular application zones without blind spots. Fig[3]
- **Power Distribution:** This graph illustrates the division of input power into absorbed, transmitted, and reflected components. A significant portion of power is observed to be absorbed within the target frequency range, demonstrating efficient antenna operation. The minimal reflected power confirms excellent impedance matching, while the transmitted power remains steady, signifying reliable energy transfer through the antenna structure. Fig[4]
- **Field Energy:** The energy-time curve shows the dynamic behaviour of stored and radiated energy in the antenna. The energy rises sharply during the excitation phase, stabilizing soon after, which reflects the effective electromagnetic energy management of the antenna. This stable behaviour is essential for ensuring consistent performance and reliability in practical vehicular applications. Fig[5] [11]
- **S-Parameters:** The S11 parameter (reflection coefficient) is a critical metric for evaluating antenna performance. The plot shows a pronounced dip below -10dB in the Point 1 (2.1951 – -21.965)) and Point 2 (6.1852GHz to -33.632) dB) range, indicating excellent impedance matching and minimal power reflection. This confirms that the antenna operates efficiently within the desired frequency band, supporting reliable obstacle detection. Furthermore, the results validate the suitability of the proposed antenna for integration into the vehicular logo. Fig [6] [12]

5.2.Discussion

The findings show a clear resonance peak in the target Point 1 (2.1951 – -21.965)) and Point 2 (6.1852GHz to -33.632)dB) frequency range, which suggests efficient power transfer and impedance matching. The power distribution is across the 2-6 GHz frequency range which emphasizes the antenna's capacity to transmit power within the targeted band effectively with little loss from absorption or reflection. The transient behavior of the antenna is depicted, which shows how the field energy changes over time. The findings show efficient energy transfer and a stable operating condition, with a sharp energy increase followed by stabilization. The antenna's far-field radiation pattern, exhibits a beneficial omnidirectional behavior in the horizontal plane that enables effective signal transmission in all directions. (Figure 4) [13]

5.3.Output Waveforms

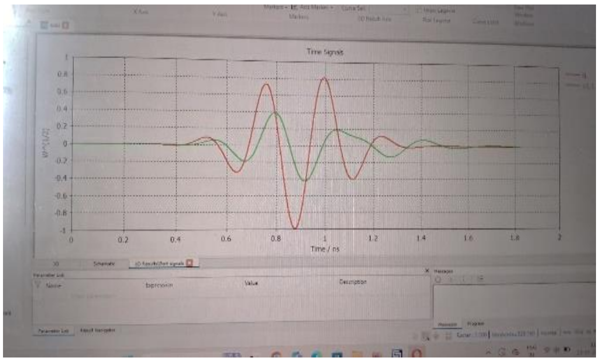

Figure 4 Time Signals

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Page No: 1465 - 1471
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https://doi.org/10.47392/IRJAEH.2025.0209

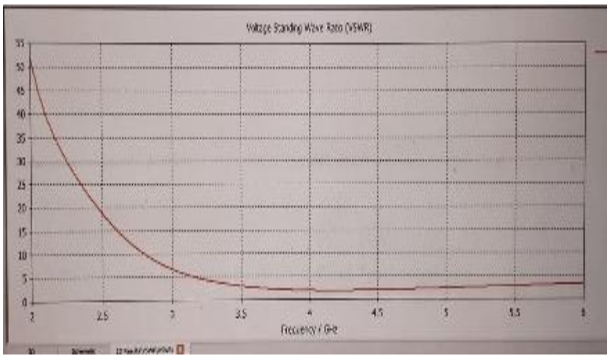

Figure 5 VSWR

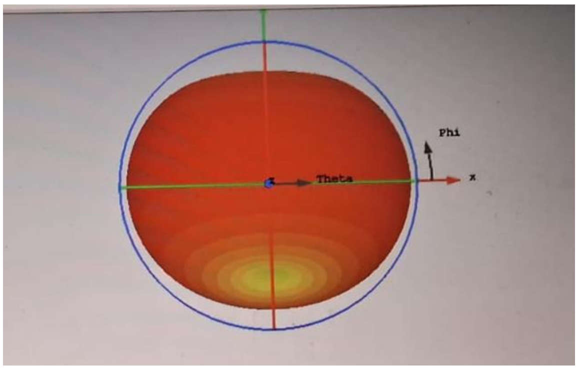

Figure 6 Radiation Pattern

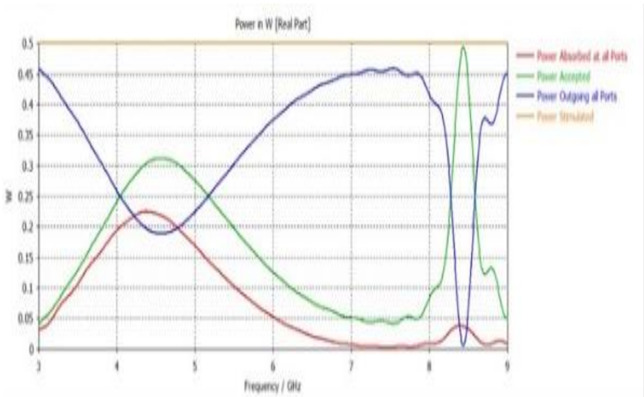

Figure 7 Power

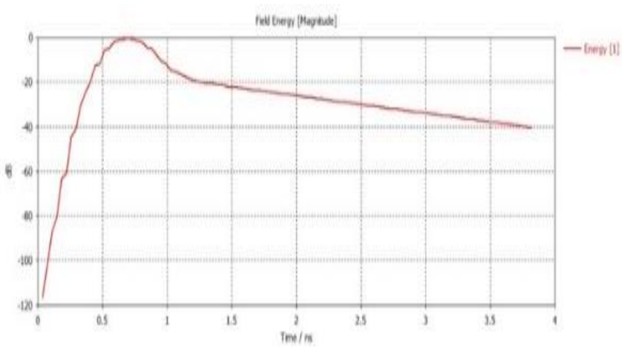

Figure 8 Energy Signal

5.4.Result Analysis

Table 2 Analysis of Each Output Wave Forms

Parameter	Patch Outputs
S – PARAMETER	Frequency range Point 1 (2.1951 – -21.965)) and Point 2 (6.1852GHz to -33.632)dB)
POWER	Power absorbed at the Frequency range (3.1634 GHz
VSWR	Increase in VSWR between (2.5 – 3.5 GHz)

The simulation results of the designed patch antenna were analyzed based on three key parameters: S-parameters, power absorption, and Voltage Standing Wave Ratio (VSWR). The S-parameter analysis demonstrated a frequency range from Point1(2.1951GHz – -21.965db) and Point2 (6.1852GHz to -33.632) dB), with the reflection coefficient (S11) varying from -21.965 dB to -33.632 dB, indicating efficient impedance matching and minimal signal reflection. The power absorption occurred at a frequency of 3.1634 GHz, highlighting the antenna's effective energy reception at this range. The VSWR results showed an increase between 2.5 GHz and 3.5 GHz, confirming the antenna's operational stability within this frequency band. These results validate the antenna's effectiveness in the specified frequency range, making it suitable for wideband communication applications. [14]

6. Diagrammatic Representation

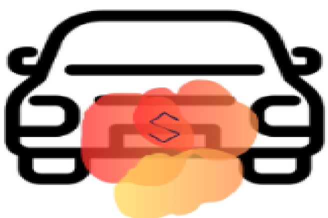

Figure 10 Front Side

This represents the logo that is being fixed in the front of the Suzuki car and it's radiation pattern around the antenna patch is given by representing with a coloured image. [15]

Figure 10 Both Front and Back View of Patch Antenna

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