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REGULAR ARTICLE

An Optimal Antenna Design for Smart Traffic Management System Using CST

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Antenna is one of the backbone and frontend device to any communication systems used for wide variety of applications including traffic management and cellular mobile phones etc. The compact size and low profile of the optimal antenna is a notable feature, enhancing its suitability for integration into small devices. Its multi-band frequency response is obtained by inserting a rectangular slot on a radiating patch of antenna, allowing for precise tuning of operation frequencies. In this research paper, we proposed a rectangular patch antenna with shorting pins that leads to optimal antenna design methodology, for this design we have considered various dimensional calculations. With the help of these parameters, we have designed and simulated the antenna using Computer Simulation Technology (CST) Microwave Studio. We then analyzed the simulation results to ensure accuracy in predicting the antenna's performance parameters. The result produces an average gain of 3 dBi with a return loss of – 15 dBi. It has operating frequency range between 2 to 6 GHz. In addition to the desired frequency and gain, it also evaluates the key parameters including bandwidth, directivity, and radiation patterns. The proposed system improves connectivity and road safety through efficient, good, and dependable communication. Finally, it may lead to a better network connectivity with improved overall functionality as well as Quality of Service (QoS) of the communication devices.

Keywords: Microstrip patch antenna, Shorting pins, FR4 substrate, S-parameters, CST microwave studio, Microstrip line feed.

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1. INTRODUCTION

The fast evolution of Intelligent Transportation Systems (ITS) has raised the need for efficient and dependable communication technology. Smooth wireless communication between cars, roadside infrastructure, and traffic control units is crucial for enhancing road safety and streamlining traffic in contemporary smart traffic management systems. For applications like collision avoidance, traffic congestion control, and autonomous vehicle coordination, real-time data exchange is made possible by vehicle-to-everything (V2X) communication, which includes Dedicated Short-Range Communication (DSRC) and Internet of Things (IoT)-based monitoring. These wireless communication networks are based on antennas, whose design must adhere to strict specifications for steady radiation characteristics, high gain, wideband operation, and small size. Microstrip patch antennas are a popular choice among different kinds of antennas because of its lightweight design, low profile, and simplicity of construction [1]. However, impedance mismatching and limited bandwidth are two drawbacks of traditional patch antennas that might impair system performance.

This work investigates the design of a microstrip patch antenna with shorting pins that is optimized for operation between 2 to 6 GHz in order to overcome these issues. The antenna is appropriate for ITS applications because the addition of shorting pins enhances impedance matching, bandwidth performance, and compactness. For real-time traffic management, the suggested antenna is made to offer strong connection, wideband capabilities, and high radiation efficiency [2].

Low latency, dependable connectivity, and smooth integration with the current traffic management system are guaranteed by a well-designed antenna operating in this frequency. Furthermore, the suggested antenna's small size makes it simple to install on cars, traffic lights, and roadside equipment without materially affecting the system's function or appearance. The performance of the suggested antenna, including return loss, radiation pattern, and impedance characteristics, is thoroughly examined in this work and verified by simulations [3].

The outcomes show that shorted patch antennas can be used for next-generation ITS applications. In order to provide smooth communication between vehicles, roadside devices, and traffic control centres, the results of this study help design scalable, effective, and affordable antenna solutions for next-generation smart traffic management systems [4]. In the end, the results enhance road safety and maximize urban mobility by advancing the development of effective, scalable, and economical

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wireless technologies for smart city transportation [5].

The organisation of the paper is, Section 2 gives the proposed methodology of the antenna design, Section 3 represents results and discussions and followed by conclusion in Section 4.

PROPOSED METHODS FOR THE ANTENNA DESIGN

The design of the microstrip patch antenna with four shorting pins is based on an FR4 substrate (ε_r = 4.4, thickness = 1.6 mm), chosen for its dielectric properties and suitability for high-frequency applications. The antenna is made up of a copper ground plane on the bottom layer and a rectangular patch on top of the substrate. The patch is excited by a microstrip line feed, which guarantees 50 Ω impedance matching for the least amount of reflection loss. To increase bandwidth and miniaturization, four shorting pins (metallic vias) are inserted between the patch and the ground plane. This makes the antenna small and effective for use in the 2–6 GHz frequency range. Applications in smart traffic management systems, where dependable connectivity and consistent radiation patterns are crucial, are best suited for this design [6].

According to the fundamental theory of the antenna, the shorting pin causes the antenna to resonate at a quarter-wavelength [11]. The following equations (1) and (2) are used to determine the size of the patch of an antenna.

$$L_p + W_p - W_{sp} = \frac{\lambda}{4} \tag{1}$$

$$\lambda = \frac{c}{fr} \tag{2}$$

Where, W_p = Width of the patch, L_p = Length of the patch, c = Speed of light, ε_r = Relative permittivity, f_r = Resonant frequency, W_{sp} = Width of the shorting pin. parameters of the antenna will be half of the parameters of the microstrip antenna which is resonant at half wavelength. The parameters of the antenna to be calculated are as follows:

Width (W_p): The equation (3) used to calculate the width of the patch is as follows:

$$W_p = \frac{c}{4fr}\sqrt{\frac{2}{\varepsilon r+1}} \tag{3}$$

Effective refractive index (ε_{eff}): This value is determined using the following equation (4):

$$\varepsilon_{eff} = \frac{\varepsilon r+1}{4} + \frac{\varepsilon r-1}{4}\left[\frac{1}{1+6\left[\frac{h}{w}\right]}\right] \tag{4}$$

***Length* (L_p):** When a patch antenna's edges have fringing, the antenna's size increases by an amount (ΔL). The actual increase in length of the patch (ΔL) can be calculated using the following equation (5):

$$\Delta L = 0.412h\left[\frac{(\varepsilon eff+0.3)\left(\frac{w}{h}+0.264\right)}{(\varepsilon eff-0.258)\left(\frac{w}{h}+0.8\right)}\right] \tag{5}$$

Where 'h' = height of the substrate.
The length (L) of the patch can be calculated using the following equation (6):

$$L_p = \frac{c}{4fr\sqrt{\varepsilon eff}} - 2\Delta L \tag{6}$$

Now the dimensions of a patch are known [11]. The length and width of a substrate are equal to that of the ground plane. The equations (7) and (8) for calculating the length (L_g) and width (W_g) of a ground plane are as follows:

$$L_g = 5 + L_p \tag{7}$$

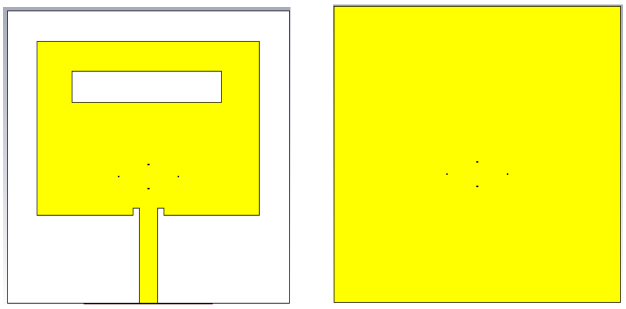
$$W_g = 5 + W_p \tag{8}$$

Impedance Matching: Impedance(Z_0) calculation formula (9):

$$Z_0 = 120\pi / \sqrt{(\varepsilon_r)}((w/h)+1.393+0.667\ln((w/h)+1.444)) \tag{9}$$

The configurations of antenna are shown in Figs. 1-4. Using the above equations, the dimensions of the patch are 28 mm × 37 mm × 0.035 mm. The ground dimensions are 33 mm × 42mm × 0.035mm are shown in Fig 2. The antenna has a relative permittivity of 4.3 and it is fed with a microstrip line feeding system with a characteristic impedance of 50 ohms by using the materials of Copper and Dielectric. This involves incorporating slots on the patch, allowing for enhanced bandwidth and frequency coverage. These slots help in improving various characteristics of the antenna such as impedance matching, bandwidth, radiation pattern, frequency, and overall performance [7].

Four shorting pins (metallic vias) are introduced between the patch and the ground plane to improve bandwidth and miniaturization, making the antenna compact and efficient for operation within the 2-6 GHz frequency range. The slots are carefully positioned and optimized to achieve the best results, which involves simulations and analysis to assess the impact of different slot dimensions and positions on the antenna's performance [8]. The table (1) consists of the parameters and their values for the antenna.



Figs. 1-2 – Top and Bottom views of antenna design

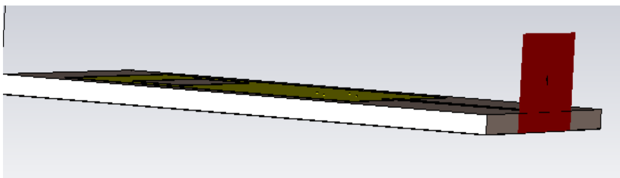


Fig. 3 – Side view of the antenna

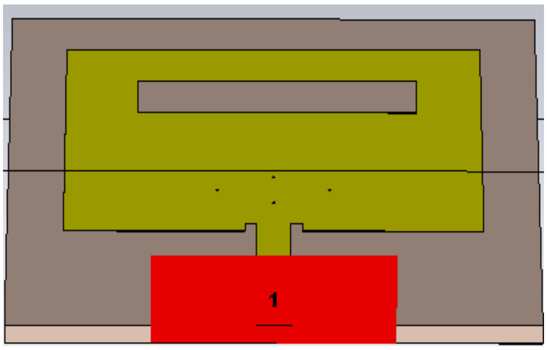


Fig. 4 – Overview of the antenna

Table 1 – Parameters of the proposed antenna

Parameters	Value(mm)
Patch length (Lp)	28
Patch width (Wp)	37
Patch thickness (hp)	0.035
Substrate thickness (hs)	1.6
Substrate length (Ls)	33
Substrate width (Ws)	42
Ground length (Lg)	33
Ground thickness (hg)	0.035
Ground width (Wg)	42
Shorting pin outer radius (D)	0.1
Shorting pin inner radius (d)	0.0
Slot length (Wsp)	1
Slot width (W5)	5

2. RESULTS AND DISCUSSION

This section describes and discusses the various parametric analyses of the optimized design, including antenna S-parameters, and 2D radiation characteristics.

The simulation results of the microstrip patch antenna with four shorting pins in CST Microwave Studio confirm its efficient performance across the 2-6 GHz frequency range, making it suitable for smart traffic management applications [9]. The S11 parameter, which represents the reflection coefficient, achieves values below -15 dB, indicating minimal power reflection and effective impedance matching is shown in Fig 5. The Voltage Standing Wave Ratio (VSWR) remains below 2, ensuring optimal power transmission between the antenna and the feedline with minimal signal loss. The radiation pattern demonstrates a stable and directional response, essential for maintaining reliable communication in real-world scenarios. The gain of the antenna, measured in dBi, highlights its ability to focus power in a specific direction, enhancing signal strength and range [10]. For triple-band frequencies at 2.1 GHz, 2.4 GHz, and 5.8 GHz covering various smart traffic management applications, rectangular saped slot is inserted on the same antenna. This setup yields gains of 2.4 dB, 5.6 dB, and 3.6 dB at the lower, central, and higher frequencies, respectively are shown in Fig 6.

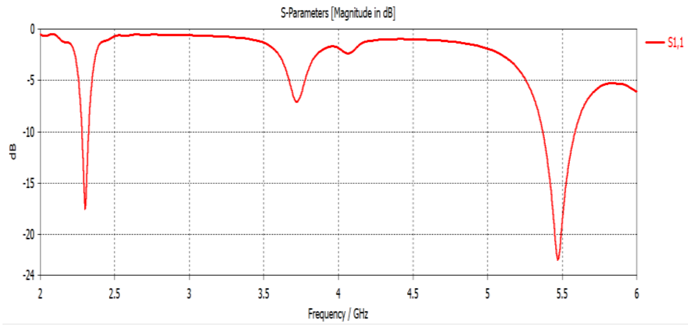


Fig. 5 – Simulated |S11| values (dB) of the Triple-band antenna versus frequency

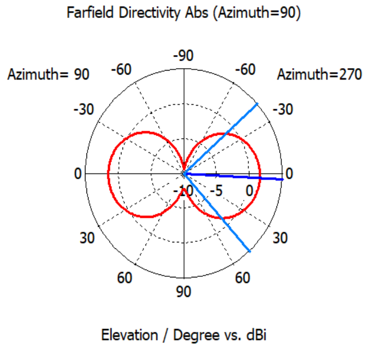


Fig 6.a

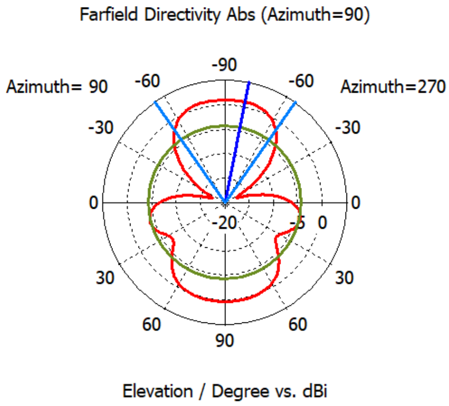


Fig 6.b

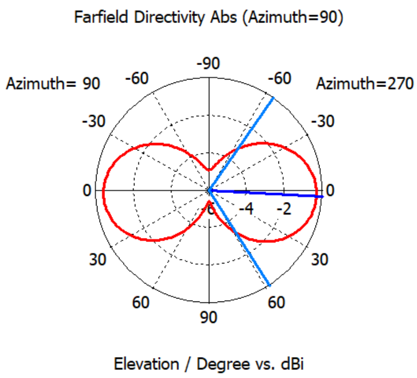


Fig 6.c

Fig 6(a, b , c). Simulated Radiation Pattern (dB) at 2.1GHz, 2.4GHz, and 5.8GHz respectively

3. CONCLUSION

This study presents the design and analysis of a microstrip patch antenna with shorting pins optimized for smart traffic management systems operating in the 2-6 GHz frequency range. The suggested antenna is more appropriate for Vehicle-to-Everything (V2X) communication in Intelligent Transportation Systems (ITS) because to its significant benefits, which include higher bandwidth, steady radiation characteristics, high gain, and improved impedance matching. Shorting pins have been shown to be a useful method for performance improvement, downsizing, overcoming the drawbacks of traditional patch antennas. The suggested antenna's small size and low profile make it extremely versatile for practical use in roadside units, vehicle networks, and smart city infrastructure. Overall, this research advances traffic control, road safety, and urban mobility by helping to build effective, affordable, and scalable antenna systems for next-generation ITS applications.

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Оптимальна конструкція антени для інтелектуальної системи управління дорожнім рухом з використанням CST

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Антена є одним з основних та інтерфейсних пристроїв будь-яких комунікаційних систем, що використовуються для широкого спектру застосувань, включаючи управління трафіком, стільникові телефони тощо. Компактний розмір та низький профіль оптимальної антени є помітною особливістю, що підвищує її придатність для інтеграції в невеликі пристрої. Її багатодіапазонна частотна характеристика досягається шляхом вставки прямокутного отвору на випромінювальну ділянку антени, що дозволяє точно налаштувати робочі частоти. У цій дослідницькій роботі ми запропонували прямокутну ділянку-антену з закорочувальними контактами, що призводить до оптимальної методології проектування антени, для цього проекту ми розглянули різні розрахунки розмірів. За допомогою цих параметрів ми спроектували та змоделювали антену за допомогою технології комп'ютерного моделювання (CST) Microwave Studio. Потім ми проаналізували результати моделювання, щоб забезпечити точність прогнозування параметрів продуктивності антени. Результат дає середній коефіцієнт посилення 3 дБі з втратами на відбиття –15 дБі. Вона має робочий діапазон частот від 2 до 6 ГГц. На додаток до бажаної частоти та коефіцієнта посилення, вона також оцінює ключові параметри, включаючи смугу пропускання, спрямованість та діаграми спрямованості. Запропонована система покращує зв'язок та безпеку дорожнього руху завдяки ефективному, якісному та надійному зв'язку. Зрештою, це може призвести до кращого мережевого з'єднання із покращеною загальною функціональністю, а також якістю обслуговування (QoS) комунікаційних пристроїв.

Ключові слова: Мікросмужкова патч-антена, Закорочувальні контакти, Підкладка FR4, S-параметри, Мікрохвильова студія CST, Лінія живлення мікросмужкової антени.