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Designing a Rectangular Patch Antenna for Vehicle Monitoring Systems

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Abstract

The growing occurrence of traffic accidents in urban regions is a cause for concern. Ensuring the safety and well-being of individuals involved in accidents is of utmost importance, and it is essential to provide them with prompt rescue operations and essential medical assistance. This research aims to develop an antenna system that operates at 2.4 GHz in the S-band (1.97 GHz-2.69 GHz) for monitoring vehicles involved in accidents. The monitoring unit will be installed into the vehicles and will need a small rectangular patch antenna to be placed on the rooftop of the vehicle for better signal reception and transmission. A thorough simulation analysis using Computer Simulation Technology software has been conducted to evaluate the performance of the antenna design. The simulation outcomes reveal that the proposed antenna offers a bandwidth of 115.991 MHz (ranging from 2.258525 GHz to 2.374516 GHz), ensuring reliable signal transmission and reception in challenging conditions. It also shows a return loss of −53.52039 dB, indicating excellent impedance matching, a Voltage Standing Wave Ratio of 1.004456 for near-perfect impedance matching, a gain of 2.55 dBi for effective signal transmission, a directivity of 4.815 dBi for focusing energy in a specific direction, and a radiation efficiency of −2.262 dB (59.43%) for converting input power into radiated electromagnetic waves efficiently. These results suggest that the antenna system will be effective and reliable for real-time signal transmission and reception in accident monitoring scenarios. Implementing this system with an optimized antenna is expected to reduce response time for rescuing accident victims, potentially saving lives and minimizing the impact of traffic accidents in urban areas.

Categories: Microwave and RF Engineering
Keywords: vehicle monitoring, return loss, rectangular patch antenna, traffic accidents, vswr

Introduction

Wireless communication for personal use has experienced a significant rise in popularity worldwide. Comparing the service quality provided in the past with the present, there has been a significant improvement [1]. The global infrastructure for terrestrial mobile communication has also expanded, resulting in satisfactory coverage for the majority of areas. However, there are still remote regions that lack coverage. To address this issue, satellite-based wireless communication offers a viable solution. One of the advantages of utilizing satellite technology in mobile communications is the ability to transmit and receive traffic through broadcast or multicast methods [2,3]. The merits of using mobile satellite communication were first realized and implemented by the Japan Aerospace Exploration Agency. They developed the Engineering Test Satellite VIII, an advanced S-band satellite. This satellite was launched into space to conduct orbital experiments and validate the various functionalities of mobile satellite communication. This technology aims to provide faster, more accurate, and error-free data from satellites, especially for traffic control in emergencies [4]. Additionally, the utilization of GPS, vehicular communication regulation, and electronic toll collection have been rapidly increasing [5].

Antennas play a crucial role in establishing seamless communication with satellites, especially in high-speed vehicle scenarios. The S-band frequency range (1.97 GHz-2.69 GHz) is widely utilized for communication applications due to its optimal balance between range and data throughput capabilities [6]. Among various antenna technologies used in vehicle communication systems, such as the monopole, microstrip patch, on-glass, bonded foil, and fractal antennas, the microstrip patch antenna is favored for its low profile, lightweight design, and ease of integration into vehicle components like the bumper or roof. However, conventional patch antennas face limitations in operating bandwidth due to a high-quality factor (Qn) [7]. To address this issue, techniques such as adjusting dielectric material thickness and substrate dielectric constant have been proposed to enhance the antenna's bandwidth and overall performance, making it more suitable for the rigorous demands of vehicle monitoring systems (VMS) [8].

A single-feed square patch antenna measuring 41 × 41 × 1.6 mm^3, featuring an inclined fractal defected ground structure for circular polarization (CP) in S-band applications, was suggested [9]. This antenna accomplished CP radiation at 2.61 GHz, exhibiting an impedance bandwidth of 5.53% and a peak gain of 4.12 dBi. This particular design is well-suited for wireless communication in the S-band, displaying satisfactory concurrence between actual and simulated outcomes, thereby augmenting axial ratio bandwidth and return loss bandwidth. A central spiral split-rectangular-shaped metamaterial absorber, encompassed by a polarization-insensitive ring resonator, attained 99.9% absorption at 3.1 GHz. The absorber showcases elevated absorption rates, rendering it efficient for radar detection at low frequencies and other S-band applications. This design underscores the utilization of split gaps and ring resonators to amplify electric field intensity and absorption capacities [10]. A compact quad-channel diplexer employing triangular and rectangular loop resonators for applications in L- and S-bands was unveiled [11]. The duplexer exhibited remarkable performance characteristics with insertion loss below 0.8 dB and return loss exceeding 21 dB at four distinct operating frequencies. Consequently, it is deemed suitable for multiband communication systems necessitating compact and effective filtering components. An exploration was conducted on a microstrip notch antenna designed for radio frequency (RF) energy harvesting in S-band applications [12]. This antenna is characterized by a notch with an inset feed, tailored for employment in satellite, radar, and air traffic control systems. Its modest dimensions, cost-efficiency, and omnidirectional emission pattern position it as a promising contender for energy harvesting purposes. A frequency-reconfigurable multimode antenna capable of functioning across the ISM, 5G-sub-6 GHz, and S-band frequencies was put forth [13]. The antenna leverages triangular-shaped monopole radiators with PIN diodes to achieve frequency reconfigurability, thereby attaining wide bandwidth and exceptional performance across multiple frequency bands. This design offers flexibility and adaptability for a variety of wireless communication scenarios.

A revised patch antenna for nano-satellite applications operating in the S-band was developed [14], showcasing enhanced performance metrics such as a return loss of less than −20 dB, a Voltage Standing Wave Ratio (VSWR) below 1.7, and a peak gain of approximately 7 dBi, thereby improving the reliability of communication links. The design of circularly polarized patch antennas for small satellites in the S-band [15] provides significant advantages such as high gain, unidirectional features, and compatibility with CubeSat setups, rendering them suitable for a variety of small satellite missions, including VMS. By utilizing a genetic algorithm, a patch antenna has been optimized for bandwidth and gain enhancement [16], crucial for effective communication in VMS. Furthermore, a compact multiband microstrip patch antenna intended for GSM/WLAN/WiMAX/DSRC/X-band satellite applications for vehicle communication with four resonant frequency bands was proposed [17], demonstrating nearly omnidirectional radiation properties and satisfactory gain levels. The efficacy of microstrip patch antennas in satellite imaging systems and GPS applications was underscored [18] due to their effectiveness in communication systems like vehicle monitoring. A circularly polarized patch antenna with double Slip Ring Resonator for vehicle-to-vehicle [19], illustrating the potential for diverse polarization and radiation characteristics across various bands, including C-band and DSRC-band, essential for vehicle-to-satellite and vehicle-to-everything communications. An innovative linearly polarized compact patch antenna designed for potential application in vehicle-to-vehicle communication was introduced [20], incorporating resonators to suppress harmonics and etching slots to achieve symmetrical current distribution. This antenna achieves a fractional impedance bandwidth of 4.0%, peak realized gain of 6.0 dBi, cross-polarization level of 40.7 dB, and front-to-back-lobe ratio of 20 dB with an efficiency of 95%. Additionally, a single-fed, single-layer, dual-band antenna with a significant frequency ratio of 4.74:1 for vehicle-to-vehicle communication was presented [21], offering a high peak gain of 7.7 dBi in the DSRC-band and 6.38 dBi in the 5G mm-wave band. A circular ring-shaped patch antenna designed for automotive communication and DSRC applications was proposed [22]. Moreover, a CPW-fed patch antenna configuration tailored for weather monitoring, air traffic control, and defense tracking applications was demonstrated [23], along with a millimeter-wave patch antenna for 5G communication on vehicles [24], a slotted patch antenna featuring an enhanced gain pattern for automotive applications [25], and a wideband circularly polarized patch antenna array for vehicle communication [26]. An E-slot microstrip patch antenna designed for vehicle-to-vehicle communication [27] is distinguished by its low profile, high gain, and wide bandwidth capabilities. A vehicle-mounted antenna with a shallow omnidirectional radiation profile in the high-frequency band was described [28]. A microstrip patch antenna operating at 2.4 GHz for S-band wireless communications was introduced [29]. A triple-band rectangular slot microstrip patch antenna was developed for Wi-Fi, Wi-MAX, and Satellite Applications [30]. A comprehensive demonstration of an S-band microstrip patch antenna design and simulation for wireless communication systems was provided [31].

In this study, a specialized antenna unit is developed to establish a seamless communication link with a geostationary satellite, even when the vehicle is in motion at high speeds. To meet the demand for compact antenna capable of tracking satellite beams, a new design known as the partial grounding inset feedline-based rectangular patch antenna is proposed. This design aims to optimize impedance matching, improve signal reception and transmission on vehicle rooftops, and address bandwidth constraints. By leveraging innovative antenna configurations, the proposed antenna significantly improves communication performance in challenging environments, ensuring dependable connectivity with satellites during rapid vehicle movement. These advancements in vehicle-to-satellite (V2S) and vehicle-to-everything (V2X) communications offer substantial advantages in terms of connectivity and reliability for a wide range of applications.

Materials And Methods

Structure of the System

The system structure comprises of four components: satellite, transmission channel, fixed ground station, and mobile ground station. The primary transmission issue arises from obstructions, which result in a loss of satellite signal reception. Additional problems include the shadowing effect caused by trees and the fading effect caused by surrounding infrastructure and trees. These effects can be mitigated by implementing directional antennas, as they diminish signal reflection. Both the fixed ground station and mobile ground station consist of various components, including antennas, up/down converters, a duplexer, a power amplifier, a low-noise amplifier, a demodulator, and a modulator. However, the satellite's system is similar to the fixed ground station and mobile ground station, except it does not include a modulator or demodulator. The satellite receives a signal, alters its frequency, amplifies weak signals, and then transmits the signal. To assess the system architecture's performance, several metrics are utilized. These metrics include G/T (Figure of Merit), EIRP (Effective Isotropically Radiated Power), and C/N0 (Carrier Power to Noise Power Ratio). G/T and EIRP evaluate the transmission and reception capabilities of the satellite, fixed ground station, and mobile ground station, while C/N0 measures the performance of the transmission channel [32-34]. Figure *1* depicts the system architecture proposed for this work.

FIGURE 1: System configuration

In addition to the system architecture depicted in the illustration above, various alternative system architectures are presented below. These architectures differ according to the specific application being considered. The utilization of satellite communication applications is primarily restricted to military and government agencies, and selected private organizations for commercial purposes due to licensing considerations [35]. Satellite communication systems offer desirable features for military applications, such as low probability of detection and protection against jamming signals [36]. Commercial satellite-based personal communications systems have been explored for military use, highlighting vulnerabilities like jamming, interception, and communications security, as well as limitations in capacity and coverage [37]. The commercial assets available, including constellations of low Earth orbit and geostationary Earth orbit satellites, can meet military security requirements through approved encryption equipment, making them valuable for missions like Desert Storm and Bosnia peacekeeping operations [38]. Despite the cost-effectiveness of satellite communication for long-distance applications, security concerns and limitations such as high bit error rates and link delays pose challenges for broader commercial use [39].

The different system structure depicted in Figure *2*, as discussed in Mishra et al. [40], aims to improve communication between fast-moving vehicles, a crucial requirement for military convoys, emergency response teams, and high-speed transportation systems. To address the challenges of maintaining connectivity between swiftly moving vehicles, technologies such as mobile ad-hoc networks and vehicle-to-vehicle (V2V) communication protocols are essential [41]. Implementing robust signal processing algorithms and adaptive networking protocols is vital to ensure reliable and low-latency communication between these vehicles [42,43]. Additionally, the advancement of Ethernet-based architectures with dependable performance and simple setups can also assist in meeting the communication needs of in-vehicle networks, particularly as vehicles are equipped with more sophisticated sensors and processors.

FIGURE 2: Different architecture for the system

The additional system architecture proposed in Figure *3* focuses on ensuring uninterrupted communication between army tanks and satellites, especially in rugged terrains where traditional infrastructure may be lacking [44]. This architecture likely involves ruggedized communication equipment capable of withstanding harsh conditions and providing secure connectivity [45]. Techniques such as satellite communication, mesh networking, and resilient routing protocols may be utilized to maintain continuous links between tanks and satellites, even in challenging terrains. These tailored communication solutions underscore the importance of advanced technologies and specialized protocols to address the unique challenges of high-speed vehicle communication and rugged terrains [46]. Moreover, the regulatory complexities and licensing considerations in satellite communication highlight the challenges involved in deploying such systems for restricted applications [47].

FIGURE 3: Additional alternative structure for the system

Vehicle Antenna Systems

The vehicular antennas must possess properties that meet the electrical, mechanical, and electromagnetic requirements. The desired characteristics can be described as follows [48-52]:

Mechanical requirements: The antenna design should prioritize lightweight construction and small size, aiming to save space and address structural concerns. However, designing a compact antenna comes with a trade-off: it results in less gain and a narrower beam width. Because of this reduced gain, the power supply to the antenna needs to be increased. Yet, vehicle batteries have constraints on supplying high power. Additionally, the antenna design should have a wide bandwidth. However, designing an antenna with a large bandwidth can cause interference with other systems and introduce an increased fading effect. When the antenna is mounted on a vehicle, it is recognized as a mechanical structure that experiences vibration effects when the vehicle is in motion at high speeds. It is also subjected to aerodynamic forces, and the sudden application of brakes can cause additional vibration effects and harmonics. These effects can be assessed by utilizing simulation tools and performing various analyses such as modal analysis and harmonic analysis.

Electrical requirements: The signal both before transmission and after reception is purely an electrical signal. According to the Friss transmission formula's link budget, the key parameter for ensuring the signal is received without being lost is input power. The only feasible way to supply power to the antenna mounted on the vehicle is through the vehicle's battery. However, it is important to note that the vehicle's battery is charged using the vehicle's fuel. Therefore, the installation of the antenna system increases the fuel consumption of the vehicle, which is undesirable.

Electromagnetic requirements: The International Telecommunication Union (ITU) governs the regulations for satellite services, specifically the authorized utilization of frequencies in different regions across the globe. In order to operate a planned system for mobile satellite communication, a legitimate license from ITU is necessary to access the allocated frequency band. For effective mobile satellite communication, the antenna installed on a vehicle should possess circular polarization to eliminate the issues of polarization tracking and other forms of signal deterioration. According to the link budget provided by the Friss transmission formula, the crucial factor for ensuring successful signal reception without any loss is the gain of both the transmitting and receiving antennas. Considering the substantial distance between the satellite and either a stationary ground station or a mobile station, the gain of the transmitting and receiving antennas ought to be set at a high level.

Monitoring Satellites

The medium and high gain antennas can track satellites by focusing their signal beams in a specific direction. This is different from omnidirectional antennas that transmit signals in all directions. The beam width of the antenna is crucial in determining the coverage area and tracking capabilities. A narrower beam width allows for more precise pointing toward satellites. The speed of the vehicle or platform on which the antenna is mounted can also impact tracking abilities, as rapid movements may require faster adjustments to maintain satellite tracking [53]. To successfully track satellites, the antenna needs to have a high level of accuracy, typically less than 1 dB, to ensure that the signal is effectively transmitted and received. Maintaining precise accuracy is essential for reliable satellite communication, especially in critical applications such as satellite ground stations and tracking systems. Satellite tracking involves beam steering and tracking mechanisms to maintain alignment with the satellite's position in space. Motors and drives are used to adjust the position of the antenna and point it toward the satellite direction, ensuring continuous communication link and data transmission [54]. In addition to traditional mechanical tracking systems, alternative methods such as electronic beam scanning can be employed for satellite tracking. Electronic beam scanning technology allows for dynamic adjustment of the antenna's beam direction without the need for physical movement, enhancing tracking capabilities and responsiveness [55-58]. The integration of advanced technologies and techniques, such as precise tracking mechanisms, electronic beam scanning, and high-gain antennas, enables precise and reliable monitoring of satellites in medium and high Earth orbits. These technologies optimize the tracking process, improve data collection, and enhance communication capabilities with satellites, ensuring the efficient operation of satellite tracking systems [59].

Antenna Structure

The work presents an innovative design for a compact partial grounding inset-fed-based rectangular patch antenna operating at 2.4 GHz. The dimensions of the dielectric substrate, ground plane, and radiating patch are crucial parameters that need to be carefully chosen to achieve the desired antenna performance [60].

Design procedure: The following equations are used to design the size of the proposed antenna:

Step 1: Determination of the Width (W) of the patch:

The width of the patch is calculated using the equation:

$$W = \frac{c}{2f_r\sqrt{\frac{\varepsilon_r - 2}{2}}}$$

Where, c = light speed in vacuum

f_r = resonant frequency

ε_r = dielectric constant of the substrate

Step 2: Determination of effective dielectric constant (ε_{reff}) :

The effective dielectric constant is calculated using the equation:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}}$$

Where, h = thickness of the substrate

Step 3: Determination of the effective length (L_{eff}) :

The effective length is determined using the equation:

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}}$$

Step 4: Determination of the length extension $(\triangle L)$:

The length extension is calculated using the equation:

$$\triangle L = 0.412h\frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)}$$

Step 5: Determination of the actual length of patch (L) :

The actual length of the patch is obtained by subtracting twice the length extension from the effective length:

$$L = L_{eff} - 2 \triangle L$$

Step 6: Determination of ground plane length (L_g) and ground plane width (W_g) :

$$L_g = L + 6h$$

$$W_g = W + 6h$$

Step 7: Inset feedline length and width of a rectangular patch antenna:

To determine the inset feedline length and width of a rectangular patch antenna, the following equations can be used:

· Inset Feedline Length (y_0) :

The inset feedline length is determined using the equation:

$$R_{in}\left(y = y_0\right) = \frac{1}{\left[2\left(G_1 \pm G_2\right)\right]cos^2\left(\frac{\pi y_0}{L}\right)}$$

· Inset Feedline Width (W_0) :

The inset feedline width is calculated using the equation:

$$W_0 = W - 2y_0tan\left(\theta\right)$$

Where:

$R_{in}\left(y = y_0\right)$ is the characteristic impedance of the microstrip feeder line at the inset length y_0 .

G_1 is the conductance term, given by

$$G_1 = \frac{1}{120}\left(\frac{W}{\lambda_0}\right) \qquad \text{when } W >> \lambda_0 \quad .$$

G_2 is the susceptance term, given by

$$G_2 = \frac{1}{90}\left(\frac{W}{\lambda_0}\right)^2 \qquad \text{when } W << \lambda_0 \quad \text{W.}$$

λ_0 is the free-space wavelength corresponding to the operating frequency.

y_0 is the inset feedline length.

L is the actual length of the rectangular patch.

W is the width of the rectangular patch.

θ is the angle of the microstrip transmission line.

Antenna design consideration: The three essential parameters highlighted for the design of a rectangular microstrip patch antenna are integral to achieving optimal performance. Here's a breakdown of each parameter and its significance:

Dielectric constant of the substrate (ε_r) : The performance of an antenna is greatly influenced by the choice of a dielectric material that possesses the appropriate dielectric constant. This factor has a significant impact on various aspects such as gain, bandwidth, radiation loss, and changes in operating frequency [61]. Additionally, the dielectric constant also affects the fringing field, which is the primary cause of radiation in microstrip patch antennas. A smaller value of εr results in wider fringes, reduced conductor loss, improved radiation, and increased bandwidth and efficiency. Conversely, a higher value of εr leads to a decrease in the patch size of the antenna. In the suggested antenna design, the substrate material chosen is FR4 lossy, which possesses a dielectric constant of 4.3. For microstrip patch antennas, the dielectric constant and the dielectric loss tangent typically range from 2.2 to 12 and 0.001 to 0.06, respectively.

Frequency of Operation (f_r) : Selecting the resonant frequency is crucial for antennas due to its significant impact on the antenna's performance and efficiency. Resonant frequency selection plays a vital role in various antenna systems, such as glide path stations [62], wireless power transfer systems [63], microstrip antennas [64], and dipole antennas [65]. The resonance frequency directly affects the antenna's ability to efficiently radiate or receive electromagnetic signals, impacting factors like power transfer efficiency, electromagnetic interference levels, bandwidth, and overall antenna functionality. By carefully choosing the resonant frequency, antenna designers can optimize performance parameters, enhance signal transmission/reception capabilities, and ensure the antenna operates effectively within its intended frequency range. Additionally, adjusting the resonance frequency can enable antennas to operate over a band of frequencies rather than a single frequency, expanding their versatility and applicability in various communication systems [66]. The chosen resonant frequency for the design is 2.4 GHz in the S-band range of 1.96 GHz-2.69 GHz. Opting for a resonant frequency of 2.4 GHz within the S-band range offers numerous advantages. It improves signal preservation, enhances system efficiency, and boosts antenna performance, making it a strategic choice for reliable, efficient, and effective VMS.

Height of Dielectric Substrate (h) : The performance of a microstrip patch antenna is greatly influenced by the height of the dielectric substrate. This height has a significant impact on various aspects such as bandwidth, surface waves, radiation efficiency, spurious feed radiation, and overall size [67]. In the case of the designed antenna, which has a substrate height of 1.4 mm, increasing the height has proven to enhance the bandwidth and provide better support for wideband operation. However, this increase also brings about challenges such as increased surface wave power, spurious feed radiation, and reduced radiation efficiency. It is crucial to strike a balance between these factors. By carefully selecting the substrate height, a compact, efficient, and high-performing antenna can be achieved, which is suitable for the intended wireless communication application. To optimize these parameters and address any potential drawbacks associated with increased substrate height, effective design strategies and meticulous material selection are necessary.

Designing and simulation procedure with Computer Simulation Technology software (Figure *4*) [68].

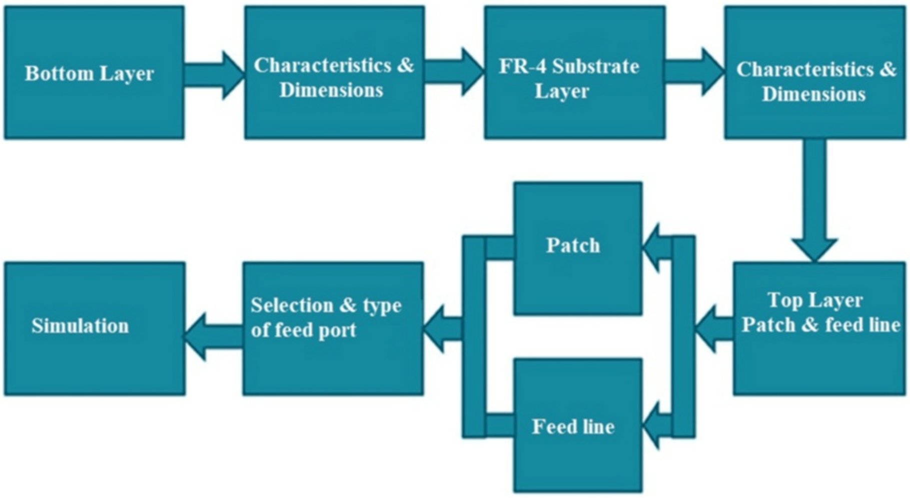

FIGURE 4: Designing a patch antenna workflow with Computer Simulation Technology software

Proposed antenna design: The antenna design shown in Figure5 consists of a rectangular shape, a FR4 dielectric substrate, a partial ground plane, and an inset-fed transmission line. The antenna is constructed on FR4 substrate with a dielectric constant of 4.3 and a thickness of 1.4 mm, with overall dimensions of 45 mm × 50 mm × 1.4 mm (LS × WS × h). It is fed through a 50 Ω inset-fed line. The specific design parameters of the antenna are listed in Table 1. By using a partial ground plane, the antenna's narrowband characteristics are transformed into wideband characteristics. This approach reduces the stored energy in the substrate, as well as the return loss, VSWR, and back lobe radiation, while simultaneously increasing the gain and bandwidth of the antenna. Additionally, the use of an inset feed approach helps to broaden the antenna's bandwidth and decrease return loss, ultimately contributing to an overall improvement in the antenna's efficiency and performance for wireless communication applications.

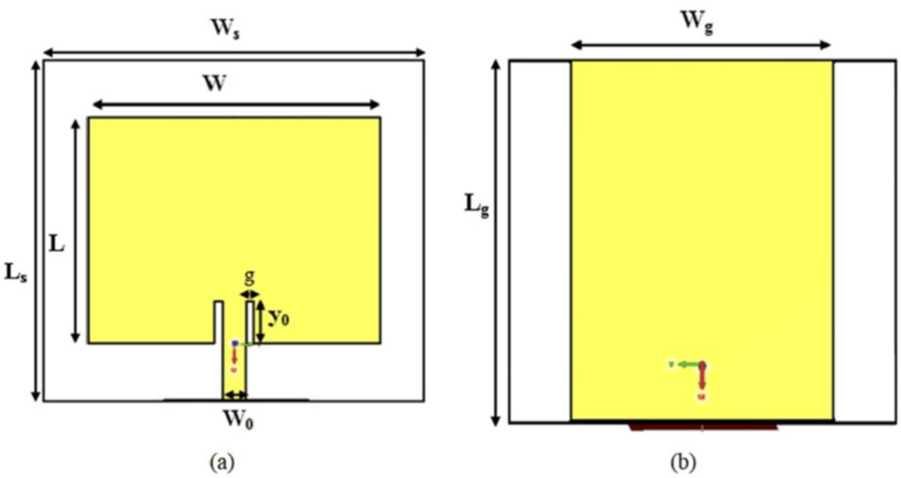

FIGURE 5: Geometry of the designed antenna unit with partial ground plane (a) Front view and (b) Back view

Parameters	Value	Parameters	Value
Substrate dielectric constant, ε_r	4.3	Patch length, L (mm)	29.83
Substrate thickness, h (mm)	1.4	Patch width, W (mm)	38.37
Substrate length, L_s (mm)	45	Copper thickness, t (mm)	0.035
Substrate width, W_s (mm)	50	Width of the feed, W_0 (mm)	3.137
Partial ground width, W_g (mm)	34	Inset length, y_0 (mm)	5.5
Partial ground length, L_g (mm)	45	Inset gap, g (mm)	1

TABLE 1: Geometrical parameters of the proposed rectangular patch antenna

Results

This section describes the performance metrics of the suggested antennas, including return loss, bandwidth, gain, directivity, radiation pattern, and efficiency. The simulation is performed on an inset length or location that is fixed because the design is meant to function at a resonant frequency of 2.4 GHz. CST (Computer simulation technology) Studio Suite Learning Edition Software has been utilized to run the simulation.

The investigation aimed to determine the effect of the width of the partial ground plane on the performance of the proposed antenna. The width of the partial ground plane was varied between 28 mm and 34 mm in order to identify the suitable width for the antenna. Table *2* provides a summary of the simulation results, showing the various outcomes that were observed as the width of the partial ground plane was changed. The antenna properties were found to exhibit variation as the width was adjusted. The results in Table *2* indicate that the minimum return loss, smaller VSWR, and maximum gain were achieved when the width of the partial ground plane was set to 34 mm. This implies that the antenna performed optimally with this width. Based on these results, the decision was made to use a width of 34 mm for the proposed antenna. Subsequent analysis and testing were then carried out using this width.

Partial ground plane width, Wg (mm)	Return Loss (dB)	VSWR	Operating Bandwidth (GHz)	Bandwidth (GHz)	Gain (dB)	Directivity (dB)	Efficiency (%)
28	–29.74	1.067716	2.251346–2.388434	0.137088	2.381	4.407	62.72
30	–34.84	1.036825	2.257599–2.388015	0.130416	2.451	4.535	61.89
32	–41.95	1.046708	2.257237–2.380615	0.123378	2.498	4.670	60.65
34	–53.52	1.004456	2.258525–2.374516	0.115991	2.55	4.815	59.43

TABLE 2: Effect of partial ground plane width changes on the antenna performance

Return Loss (S_{11})

Return loss is a crucial parameter in antenna performance, indicating the amount of power reflected back from the antenna compared to the transmitted power. It is typically measured in decibels (dB) and is related to the reflection coefficient (Γ). For most practical applications, especially in communication systems, having an antenna with a low return loss (typically less than −10 dB) is desirable. This low return loss indicates good impedance matching and efficient power transfer. On the other hand, high return loss values are generally undesirable because they signify poor impedance matching and inefficient power transfer. This can lead to reduced performance of the antenna or device. Figure *6* depicts the return loss (S_{11}) for a suggested antenna. The recommended antenna shows a low return loss of –53.52039 dB at the resonant frequency of 2.3144 GHz, showcasing superior impedance matching. This design achieves significantly better return loss results compared to the findings in studies [29-31]. Typically, a return loss below −10 dB is considered good, but –53.52039 dB represents exceptional performance.

This remarkable return loss corresponds to a reflection coefficient of 0.00210853 or approximately 0.210853% (i.e. only 0.210853% of the incident energy is reflected back from the antenna, while approximately 99.789147% (100%-0.210853%) of the incident energy is either transmitted or absorbed by the antenna), signifying minimal energy reflection and enhanced signal radiation crucial for reliable communication systems like VMS. The improved impedance matching in the recommended antenna design not only reduces power wastage but also enhances overall performance, making it highly effective for real-time data transmission and reception, surpassing previous designs in terms of effectiveness and reliability [29-31].

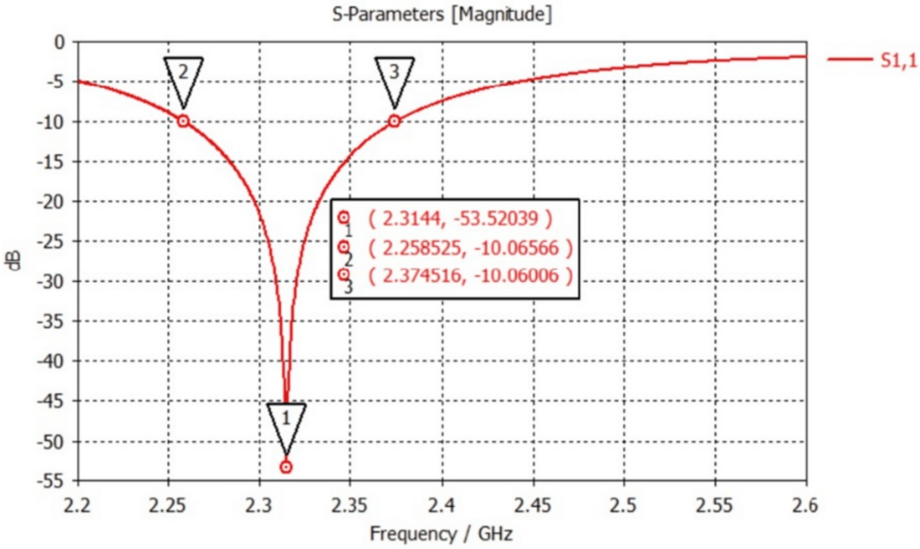

FIGURE 6: Return loss of the proposed antenna unit

Impedance Bandwidth

Impedance bandwidth is the range of frequencies over which the antenna maintains acceptable performance, for example, with a return loss below a certain threshold, such as −10 dB. The bandwidth can be calculated by using the return loss graph. As can be seen from Figure 6, the suggested antenna has an impedance bandwidth of 0.115991 GHz (115.991 MHz) from 2.258525 GHz to 2.374516 GHz, which is better than the reported bandwidths in studies [29-31]. This wider impedance bandwidth enables the antenna to operate effectively over a broader range of frequencies, enhancing its versatility and compatibility with various communication systems. A larger bandwidth is advantageous because it allows the antenna to accommodate a larger spectrum of signals, making it suitable for different applications and environments. This increased bandwidth ensures that the antenna can handle variations in frequency due to changing operational conditions, thereby maintaining reliable communication links in VMS.

Voltage Standing Wave Ratio

Voltage Standing Wave Ratio (VSWR) is a measure of how well an antenna is matched to the impedance of the transmission line it is connected to. It is the ratio of the maximum voltage (standing wave) to the minimum voltage along the transmission line. A VSWR value of 1 indicates perfect impedance matching between the antenna and the transmission line, which means that all of the power is efficiently transferred from the source to the load without any reflections. Higher VSWR values indicate poor impedance matching, which can result in signal loss, reflections, and decreased antenna performance. Figure 7 illustrates the VSWR for a proposed antenna. The proposed antenna has a VSWR value of 1.004456 at a frequency of 2.314513 GHz. This VSWR value close to 1 indicates that the antenna is well matched to the transmission line at this frequency, signifying effective impedance matching, ensuring efficient power transfer, and minimal signal loss. Maintaining a VSWR value near 1 is essential for optimal antenna performance, as higher VSWR values indicate poor matching, leading to signal degradation and reflections. Effective impedance matching enhances system efficiency and signal integrity, highlighting the importance of minimizing VSWR for maximizing antenna performance and overall system effectiveness.

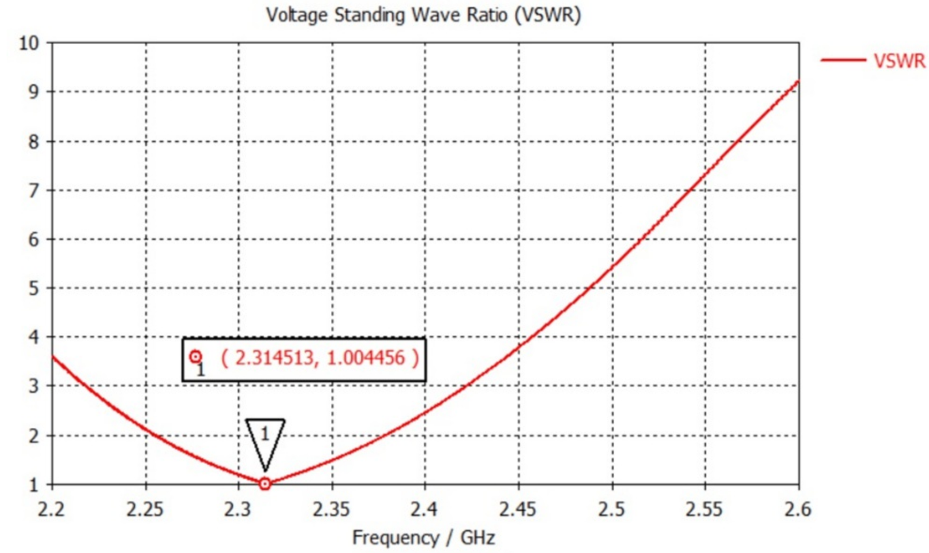

FIGURE 7: VSWR of the proposed antenna unit

Gain

The antenna's gain is a crucial parameter that characterizes its capacity to focus or concentrate RF energy in a particular direction during transmission or to receive energy from a specific direction during reception. It quantifies how efficiently the antenna converts input power into radio waves in a specified direction compared to an isotropic radiator, which evenly radiates power in all directions. Gain is commonly quantified in decibels (dB) and is frequently expressed relative to an isotropic antenna (dBi) or a dipole antenna (dBd). High-gain antennas are optimal for targeted, long-distance communication, making them suitable for point-to-point connections and scenarios where directionality is vital. These antennas focus the RF energy into a narrow beam, boosting signal strength and expanding communication range in a specific direction. Examples include satellite dishes, parabolic antennas, and Yagi-Uda antennas. On the other hand, low-gain antennas offer broad, omnidirectional coverage, making them versatile and simpler to deploy for general communication requirements. These antennas evenly distribute RF energy in all directions, which is advantageous for scenarios where signals must be transmitted or received simultaneously in multiple directions. Examples include dipole antennas and monopole antennas. The illustrations in Figure *8* and Figure *9* show that the antenna being proposed exhibits a gain of 2.55 dBi at a frequency of 2.4 GHz. This means that the antenna is able to concentrate the transmitted power in a specific direction, as opposed to an isotropic radiator. The antenna proves to be highly effective at the 2.4 GHz frequency, making it ideal for use in applications that operate within this frequency range. This makes the antenna a great choice for vehicle monitoring and tracking systems, where dependable communication is critical.

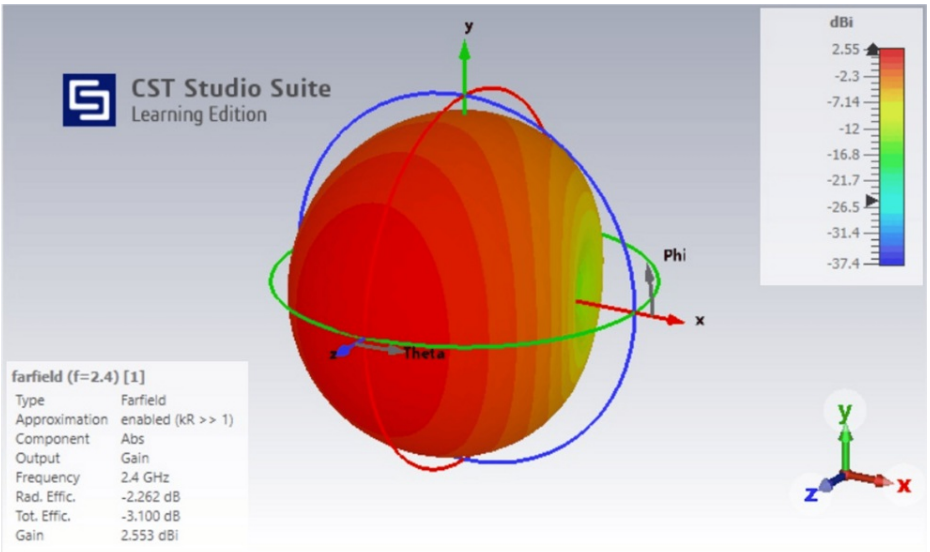

FIGURE 8: Far-field 3D gain of the proposed antenna unit

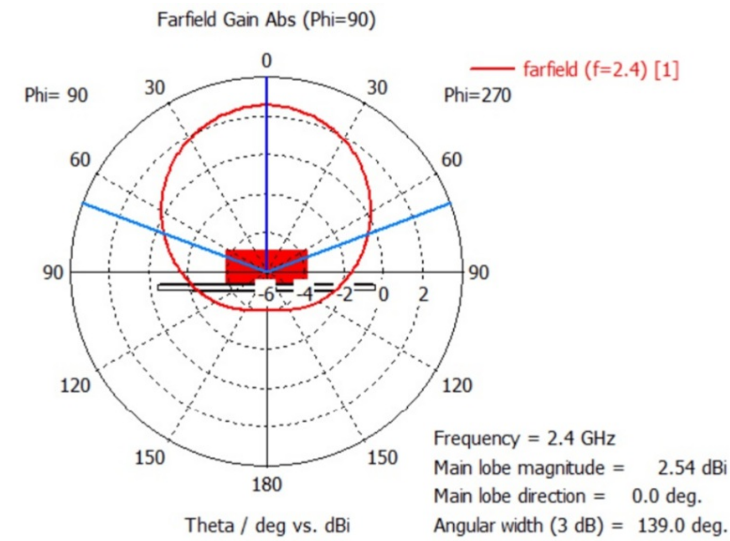

FIGURE 9: Far-field 2D gain of the proposed antenna unit

Directivity

Directivity refers to the ability of an antenna to efficiently focus energy in a specific direction during the transmission or reception of signals. It is measured by comparing the strength of radiation in the antenna's primary direction to that of an isotropic antenna, which emits radiation equally in all directions. Antennas with high directivity concentrate energy into a narrow beam, making them ideal for long-distance signal transmission or reception in a specific direction. Conversely, antennas with low directivity distribute energy more evenly, providing broader coverage suitable for multiple directional signals. The directivity of the proposed antenna is illustrated in Figures *10* and 11. This antenna has a directivity of 4.81 dBi at a frequency of 2.4 GHz, indicating a moderate level of directivity. This means that the antenna can efficiently concentrate energy more effectively than an isotropic antenna while also offering wide coverage. This makes the antenna a versatile option for applications like vehicle tracking and monitoring, as it strikes a good balance between directivity and coverage.

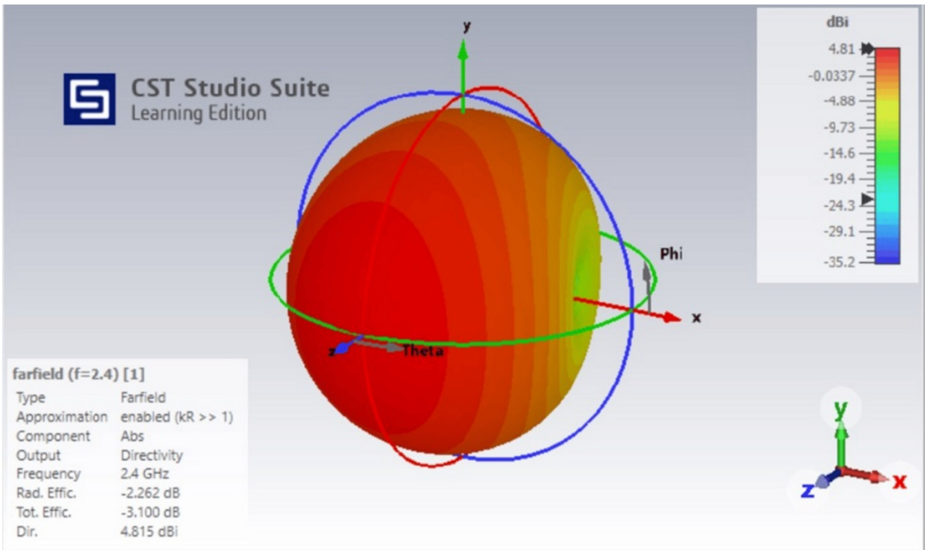

FIGURE 10: Far-field 3D directivity of the proposed antenna unit

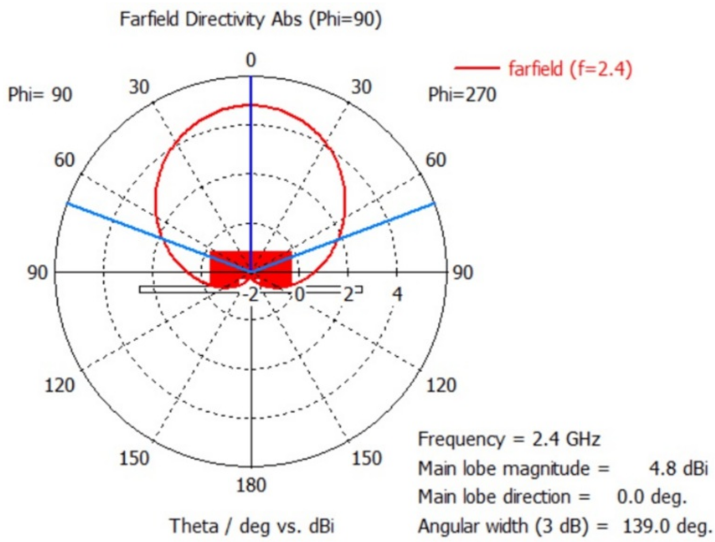

FIGURE 11: Far-field 2D directivity of the proposed antenna unit

Efficiency

Efficiency is an important factor in antenna design as it directly affects the performance of the antenna. A higher efficiency means that more of the input power is being effectively radiated, resulting in better signal transmission and reception. In the case mentioned, the antenna achieved an efficiency of −2.262 dB (59.43%). Efficiency is typically measured in decibels (dB) and represents the ratio of radiated power to input power. A negative efficiency value indicates that some power is being lost, which could be due to conductor and dielectric losses in the materials. It is desirable for the antenna efficiency to be as high as possible, ideally close to 100%. This ensures that the majority of the input power is being effectively converted into radiated power, maximizing the antenna’s performance. However, achieving very high efficiency can be challenging as it requires minimizing losses in the antenna design and construction. Efficiency can be influenced by various factors such as the design of the antenna, the choice of materials, and the operating frequency. Antenna designers strive to optimize these factors to maximize efficiency and overall antenna performance.

Summary of the Simulated Results

Table *3* presents the results of simulations conducted on the developed antenna. The following performance parameters were evaluated: resonant frequency, return loss (S11), VSWR, bandwidth, gain, directivity, and efficiency. These parameters provide important insights into the performance and effectiveness of the antenna.

Performance Parameters	Proposed Antenna
Resonant frequency (GHz)	2.40
Return loss (dB)	–53.52039
VSWR	1.004456
Bandwidth (MHz)	115.991
Gain (dBi)	2.55
Directivity (dBi)	4.81
Efficiency	–2.262 dB (59.43%).

TABLE 3: Summary of the simulated results of the proposed antenna

Discussion

The proposed antenna for VMS, designed using CST Studio Suite Learning Edition Software, demonstrates exceptional performance metrics essential for real-time accident monitoring in urban environments. With a bandwidth of 115.991 MHz, return loss of –53.52039 dB, VSWR of 1.004456, a gain of 2.55 dBi, and directivity of 4.81 dBi, the antenna ensures stable communication links and reliable data transmission. The strategic rooftop placement of these antennas aims to enhance signal pathways by minimizing obstructions and maximizing the line of sight, which is a critical feature in dense urban areas where signal path loss can significantly impact communication reliability. Despite a radiation efficiency of 59.43%, which is slightly below optimal at –2.262 dB, the overall design remains robust for supporting emergency response systems by streamlining data transmission and potentially reducing response times.

Various researchers [29-31] have conducted studies to improve antenna performance by exploring diverse strategies including size augmentation, which traditionally leads to larger antenna footprints. Table *4* encapsulates a comparative analysis showcasing that the proposed antenna not only surpasses previous designs in return loss, VSWR, and bandwidth but also adheres to S-band application requirements more compactly. Despite some limitations, the developed antennas fulfill all specified criteria and demonstrate a competitive edge in terms of compactness and performance metrics. Moreover, the suggested antenna is versatile and can be applied across a wide range of wireless communication standards, including Bluetooth (2.4 GHz-2.485 GHz), WiMAX (2.3 GHz-2.4 GHz), Microwave ovens (2.4 GHz-2.48 GHz), RFID (2.4 GHz-2.5 GHz), S-Band (2.3 GHz-2.4 GHz), Wireless Communication Services (2.345 GHz-2.360 GHz), and 4G LTE (2.3 GHz-2.315 GHz). Future research should focus on optimizing the antenna design to achieve higher efficiency and gain. This could involve exploring innovative materials and advanced design methodologies. Additionally, assessing the long-term durability and reliability of the antenna in diverse environmental conditions is crucial for ensuring sustained performance. Addressing these aspects will bridge existing gaps and enhance the robustness of antenna systems for urban vehicle monitoring and other critical applications.

Ref. Nos	Antenna Size (mm^3)	Return Loss (dB)	VSWR	Operating Bandwidth (GHz)	Bandwidth (MHz)	Gain (dB)	Efficiency (%)
[29]	75.85 × 57.23 × 1.6	–51.89	1.005	2.361–2.435	74	----	----
[30]	53 × 53 × 1.6	–27.2, –28.9, –28.9	----	----	----	1.24, 3.57, 3.28	----
[31]	100 × 100 × 1.6	–13.772	1.5152	3.513–3.4903	23.6	7.55 dBi	89.56
This work	45 × 50 × 1.4	–53.52039	1.004456	2.258525–2.374516	115.991	2.55 dBi	59.43

TABLE 4: Comparisons of the previous and present works

Conclusions

In this article, a compact antenna system for monitoring vehicles using CST Studio Suite Learning Edition Software has been successfully designed and simulated. The simulation results show that the proposed antenna meets the criteria for vehicular antennas and is suitable for monitoring vehicles. The optimized performance metrics of the antenna, including bandwidth, return loss, VSWR, gain, directivity, and radiation efficiency, ensure reliable real-time signal transmission and reception, ultimately improving safety and response times in urban areas. Although the antenna faced challenges related to radiation efficiency, further optimization could enhance its performance by exploring different techniques, configurations, and materials. Future research on MIMO antennas for VMS, which use MIMO technology to improve communication abilities, reduce antenna size, and boost gain, holds promise for enhancing monitoring and communication in various environmental conditions.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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Disclosures

Human subjects: All authors have confirmed that this study did not involve human participants or tissue. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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References

1. Zheng J, Wang R, Li Q, Wang X: Research on Key Technologies of Satellite Mobile Communication System.

In 2022 IEEE 5th International Conference on Electronics and Communication Engineering (ICECE). Xi'an, China; 2022. 34-38. 10.1109/ICECE56287.2022.10048610

2. Chini P, Giambene G, Kota S.: A survey on mobile satellite systems. International Journal of Satellite Communications and Networking. 2010, 28:29-57. 10.1002/sat.941
3. Kim J, Ham D, Kim T, et al.: Survey on Satellite-Mobile Code Offloading. In 2022 13th International Conference on Information and Communication Technology Convergence (ICTC). Jeju Island, Republic of Korea; 2022. 921-923. 10.1109/ICTC55196.2022.9952857
4. Zheng J, Fei L, Xu J, Chen H: Design of Integrated Service Platform based on Satellite Mobile Communication System. In 2019 IEEE 2nd International Conference on Electronics and Communication Engineering (ICECE). Xi'an, China; 2019. 138-142. 10.1109/ICECE48499.2019.9058509
5. Sah HN: A brief history of mobile generations and satellite wireless communication system. Journal of Emerging Technologies and Innovative Research. 2017, 4:1211-1216.
6. Lakshmi GR, Tatineni M: Design of Glass-based Antenna for Effective Vehicular Communication. In 2023 7th International Conference on Trends in Electronics and Informatics (ICOEI). Tirunelveli, India; 2023. 285-291. 10.1109/ICOEI56765.2023.10125689
7. Zhang Z, Li M, Dai Q, et al.: Compact, wideband, dual-band polarization and pattern diversity antenna for vehicle communications. IEEE Transactions on Antennas and Propagation. 2023, 71:4528-4533. 10.1109/TAP.2023.3243855
8. Yadav MV, Yadav SV, Baudha S, et al.: A smart vehicle antenna for defence and satellite communication. Autonomous Vehicles. 2022, 2:33-46. 10.1002/9781394152636.ch3
9. Gupta S, Kanaujia BK, Dalela C, et al.: Design of circularly polarized antenna using inclined fractal defected ground structure for S-band applications. Electromagnetics. 2020, 40:2526-540. 10.1080/02726343.2020.1821336
10. Sakib S, Hoque A, Rahim SK, et al.: A central spiral split rectangular-shaped metamaterial absorber surrounded by polarization-insensitive ring resonator for S-band applications. Materials. 2023, 16:1172. 10.3390/ma16031172
11. Roshani S, Yahya SI, Mezaal YS, et al.: Design of a compact quad-channel microstrip diplexer for L and S band applications. Micromachines. 2023, 14:553. 10.3390/mi14030553
12. Mishra NK, Sharma SK: Design Microstrip Notch Antenna for RF Energy Harvesting In S-Band Applications. In 2023 11th International Conference on Emerging Trends in Engineering & Technology - Signal and Information Processing (ICETET - SIP). Nagpur, India; 2023. 1-4. 10.1109/ICETET-SIP58143.2023.10151499
13. Ghaffar A, Li XJ, Awan WA, et al.: Design and realization of a frequency reconfigurable multimode antenna for ISM, 5G-sub-6-GHz, and S-band applications. Applied Sciences. 2021, 11:1635. 10.3390/app11041635
14. Barbosa MJC, Casilao PLR, Fernando RAO, et al.: A New Modification Approach to Enhance the EM Performance of an S-Band Patch Antenna for Nanosatellite Application. In 2022 IEEE Asia-Pacific Conference on Geoscience, Electronics and Remote Sensing Technology (AGERS). Surabaya, Indonesia; 2022. 99-103. 10.1109/AGERS56232.2022.10093609
15. Kaur R, Mayank M, Tandon T, et al.: S-Band Patch Antenna System for CubeSat Applications. In Advances in Information and Communication: Proceedings of the 2021 Future of Information and Communication Conference (FICC). 2021, 1:102-112. 10.1007/978-3-030-73100-7_8
16. Jayasinghe JMJ W, Uduwawala DN: Optimization of the performance of patch antennas using genetic algorithms. Journal of the National Science Foundation of Sri Lanka. 2013, 41:113-120. 10.4038/jnsfsr.v41i2.5705
17. Yalduz H, Cizmeci H : Design and analysis of multi-band compact microstrip antenna in gsm1900/wlan/wimax/dsrc/x-band frequency bands for vehicle applications. Journal of Scientific Reports-A. 2023, 52:407-418. 10.59313/jsr-a.1201301
18. Karahan M, Inal M, Dilmen A, et al.: Microstrip patch antenna design at 10 GHz for X band applications. European Journal of Theoretical and Applied Sciences. 2024, 2:384-393.
19. Zaw KK, Khin EE, Oo T, et al.: Compact design of circularly polarized microstrip patch antenna with double slip ring resonator for vehicle-to-vehicle communication. Journal of Engineering Researcher and Lecturer . 2024, 3:1-17. 10.58712/jerel.v3i1.122
20. Gangwar D, Nayak AK, Patnaik A: Design and Testing of a Microstrip Patch Antenna for Vehicle-to-Vehicle Communication. In 2022 IEEE Microwaves, Antennas, and Propagation Conference (MAPCON). Bangalore, India; 2022. 1218-1221. 10.1109/MAPCON56011.2022.10047218
21. Govindarajulu SR, Tarek MNA, Guerra MR, et al.: Modified U slot patch antenna with large frequency ratio for vehicle-to-vehicle communication. Sensors. 2023, 23:6108. 10.3390/s23136108
22. Reddy YB, Prasad AM, Veeraswamy K: Circular Ring-shaped Patch Antenna for Automotive Communication and DSRC Applications. In 2022 IEEE Microwaves, Antennas, and Propagation Conference (MAPCON). Bangalore, India; 2022. 1880-1885. 10.1109/MAPCON56011.2022.10047547
23. Sathuluri MR, Do Saikumar T, Reddy JVG, et al.: A CPW Fed Patch Antenna Design for Weather Monitoring, Air Traffic Control and Defense Tracking Applications. Fourth International Conference on Computing Methodologies and Communication (ICCMC). Erode, India; 2020. 996-999.
24. Liu H, Yang J: Millimeter Wave Patch Antenna for Vehicle-Mounted 5G Communication. In 2022 14th International Conference on Computer Research and Development (ICCRD). Shenzhen, China; 2022. 399-404. 10.1109/ICCRD54409.2022.9730417
25. Maddio S, Pelosi G, Righini M, et al.: A slotted patch antenna with enhanced gain pattern for automotive applications. Progress in Electromagnetics Research Letters. 2021, 95:135-141. 10.2528/PIERL20110103.
26. Yan YD, Jiao YC, Zhang W: Broadband Circularly Polarized Patch Antenna Array for Vehicle Communication. In 2018 11th UK-Europe-China Workshop on Millimeter Waves and Terahertz Technologies (UCMMT). HangZhou, China; 2018. 1-2. 10.1109/UCMMT45316.2018.9015715
27. Suriyan K, Ramaingam N: Microstrip patch antenna review on various parameters, methods and its applications. International Journal of Informatics and Communication Technology. 2023, 12:32-37. 10.11591/ijict.v12i1.pp32-37

28. Cho SY, Chung JY: Low-profile vehicle-mounted antenna with omnidirectional radiation pattern at high-frequency band. Journal of Korean Institute of Electromagnetic Engineering and Science . 2021, 32:223-232. 10.5515/KJKIEES.2021.32.3.223
29. Abdulhussein AM, Khidhir AH, Naser AA: 2.4 GHz microstrip patch antenna for S-band wireless communications. Journal of Physics: Conference Series. 2021, 2114:012029. 10.1088/1742-6596/2114/1/012029
30. Hossain MB, Hossain MF: Design and performance analysis of a triple-band rectangular slot microstrip patch antenna for Wi-Fi, Wi-Max and Satellite applications. International Journal of Electronics and Telecommunications. 2022, 68:217-222. 10.24425/ijet.2022.139870
31. Rana MS, Islam SI, Al Mamun S : An S-band microstrip patch antenna design and simulation for wireless communication systems. Indonesian Journal of Electrical Engineering and Informatics. 2022, 10:945-954. 10.52549/ijeei.v10i4.4141
32. Islamov I, Safarli A: Modelling and research of an antenna system for transmitting and receiving information in satellite systems. Transport and Telecommunication. 2023, 24:297-308.10.2478/ttj-2023-0024
33. Tawalbeh L: The NICE Cyber Security Framework. System Architecture. Springer, Cham; 2020. 10.1007/978-3-030-41987-5_9
34. Sreenivasulu. (An Antenna System). https://www.patentguru.com/EP4026199A1.
35. Haberman TL, Miles C, Cardoza MA: Satellite Communications as a Viable Method for Biometric Record Transfer in Field Biometric Devices. In 2009 IEEE 3rd International Conference on Biometrics: Theory, Applications, and Systems. Washington, DC, USA; 2009. 1-6. 10.1109/BTAS.2009.5339065
36. Biglieri E: Outer Space-A New Dimension of the Arms Race. System aspects in military satellite communications. Routledge, 2021. 189-196.
37. Shah SMJ, Nasir A, Ahmed H: A survey paper on security issues in satellite communication network infrastructure. International Journal of Engineering Research and General Science. 2014, 2:887-900.
38. Mahoney T, Kerr P, Felstead B, et al.: An Investigation of the Military Applications of Commercial Personal Satellite-Communications Systems. MILCOM 1999. IEEE Military Communications. Conference Proceedings (Cat. No. 99CH36341). Atlantic City, NJ, USA; 1999. 1:112-116. 10.1109/MILCOM.1999.822653
39. Hoernig O, Sood D: Military Applications of Commercial Communications Satellites. In MILCOM 1999. IEEE Military Communications. Conference Proceedings (Cat. No. 99CH36341). 1999, 1:107-111. 10.1109/MILCOM.1999.822652
40. Mishra P, Kar S, Lin C, et al.: Enabling robust communication among military ground vehicles using multi-connectivity. SAE International Journal of Advances and Current Practices in Mobility. 2024, 6:111-120. 10.4271/2023-01-0110
41. Ström EG, Ekiz L, Abbas T, et al.: Vehicular Communication Environments. Cooperative Radio Communications for Green Smart Environments. River Publishers, 2016. 30. 10.1201/9781003337720-4
42. Hamarsheh Q, Daoud OR, Al-Akaidi M, et al.: Robust vehicular communications using the fast-frequency-hopping-OFDM technology and the MIMO spatial multiplexing. International Journal of Communication Networks and Information Security. 2022, 14:19-25. 10.17762/ijcnis.v14i1.5216
43. Walrand J, Turner M, Myers R: An Architecture for In-vehicle Networks. IEEE Transactions on Vehicular Technology. 2021, 70:6335-6342. 10.1109/TVT.2021.3082464
44. Kumaran R, Arun SG, Adepu R : Design and Development of Fuel Tank for High Mobility Military Vehicle. International Conference on Automotive Materials and Manufacturing AMM 2023. SAE Technical Paper. 2023. 10.4271/2023-28-1342
45. Mentus OV, Panteleimon IN, Yakhin IH, et al.: The Main Directions of the Concept of Building a Satellite Communication Network for Providing Access to Communication Services for Residents of Remote Areas of the Russian Federation. Trudy NIIR. 2022 . 10.34832/niir.2022.10.3.001
46. Ilie CO, Barothi L, Marinescu M, et al.: Aspects of electric transmission implementation on a battle tank. IOP Conference Series: Materials Science and Engineering. 2022, 1220:012017. 10.1088/1757-899X/1220/1/012017
47. Earley LD: Communication in Challenging Environments: Application of LEO/MEO Satellite Constellation to Emerging Aviation Networks. In 2021 Integrated Communications Navigation and Surveillance Conference (ICNS). Dulles, VA, USA; 2021. 1-8. 10.1109/ICNS52807.2021.9441549
48. Shin Y, Kim J, Sung S, Oh J: Antenna Apparatus for Vehicles, and Method of Receiving Broadcasting by Using the Antenna Apparatus. U.S. Patent No. 11,967,756. U.S. Patent and Trademark Office, Washington, DC; 2024.
49. Boyes SJ : Vehicle Antenna Apparatus, Method of Use and Manufacture. U.S. Patent Application 17/627,284. 2022.
50. Ohno S, Hayakawa K, Sone T: Vehicle Antenna Device. U.S. Patent 10,355,335. 2019.
51. Masato T: Vehicle-mounted Antenna Device. 2020.
52. An Q: Vehicle Antenna Device. 2011;
53. Timoshenko AV, Babkin YV, Silantyev AB, et al.: Control of Multi-Scanning Radar Monitoring of Space Objects on Medium and High Orbits. In 2021 Systems of Signal Synchronization, Generating and Processing in Telecommunications (SYNCHROINFO). Kaliningrad, Russia; 2021. 1-6.
54. Bhanu D, Pratap D: System and Method for Monitoring Operations in a Satellite Communication System. 2015.
55. Sakr MESM, Hassan MAM: Satellite tracking control system using optimal variable coefficients controllers based on evolutionary optimization techniques. El-Cezerî Journal of Science and Engineering. 2023, 10:326-348. 10.31202/ecjse.1214722
56. Zhao L, Zhao R, Shi R, Li Q: Beam Tracking Method and Apparatus. U.S. Patent Application No. 17/043,630. 2021.
57. DiFonzo DF, Turpin JP: Dynamic Interference Reduction for Antenna Beam Tracking Systems. U.S. Patent No. 10,797, 381. U.S. Patent and Trademark Office, Washington, DC; 2020.
58. Su X, Gao Q, Tamrakar R, et al.: Beam Scanning and Search Tracking Method and Device. U.S. Patent No. 10,778,307. U.S. Patent and Trademark Office, Washington, DC; 2020.

59. Lin Z, Zhitong Z, Shouquan D, et al.: Antenna Tracking Method based on Low and Medium Orbit Constellation Satellites. 2018.
60. Balanis CA: Antenna Theory: Analysis and Design. John Wiley & Sons, New York; 2016. 4th:
61. Hanumante V, Roy S: Comparative Study of Microstrip Patch Antenna Using Different Dielectric Materials. In 9th International Conference on Microwaves, Antenna, Propagation and Remote Sensing (ICMARS-2013). Jodhpur, INDIA; 2013. 56-60. 10.6084/M9.FIGSHARE.1246838
62. Mahendran C, Vijayaraj M: Resonant frequency analysis using perturbation and resonant cavity method in printed dual band antenna for WiMAX application. Applied Computational Electromagnetics Society Journal. 2023, 382:117-128. 10.13052/2023.ACES.J.380206
63. Park J, Shin Y, Kim J, et al.: Resonant Frequency Selection Method for Wireless Power Transfer System Considering Electromagnetic Interference Reduction. In 2019 IEEE International Symposium on Electromagnetic Compatibility, Signal & Power Integrity (EMC+SIPI). New Orleans, LA, USA; 2019. 635-638. 10.1109/ISEMC.2019.8825299
64. Bukharin V, Voytovich N: Selectivity of a Resonant Cavity Antenna. ITM Web of Conferences. 2019, 30:05033. 10.1051/itmconf/20193005033
65. Yu-Bo T, Su-Ling Z, Jing-Yi L: Modeling resonant frequency of microstrip antenna based on neural network ensemble. International Journal of Numerical Modelling: Electronic Networks, Devices and Fields. 2011, 24:78-88. 10.1002/jnm.761
66. Rao CS: Design of resonance frequency variable dipole antenna. Journal of Emerging Technologies and Innovative Research. 2018, 5:872-874.
67. Singh I, Tripathi VS: Micro strip patch antenna and its applications: a survey. International Journal of Computer Technology and Applications. 2011, 2:1595-1599.
68. Shinde RV, Gabane B, Mujawar TH, et al.: Antenna design and fabrication with circular microstrip patch: a review. Journal on Today’s Ideas - Tomorrow’s Technologies. 2020, 8:65-71. 10.15415/jotitt.2020.82009