BACHELOR OF SCIENCE IN ELECTRONIC AND TELECOMMUNICATION ENGINEERING

Design of a Microstrip Patch Antenna for Vehicle to Vehicle Communication

Submitted by

Rihan Chowdhury

T191067

Supervised by

Mohammed Jashim Uddin

Associate Professor

Department of ETE

International Islamic University Chittagong

Department of Electronic and Telecommunication Engineering(ETE)

International Islamic University Chittagong

Kumira, Sitakunda, Chattogram-4318, Bangladesh.

February, 2024

ACKNOWLEDGEMENT

All praises to Almighty Allah (SWT)

We would also like to thank our thesis supervisor and coordinator, Mohammed Jashim Uddin for his sincere feedbacks and constant inspiration, patience, necessary guidance, continuous assistance, constructive suggestions, and technical support. His mentorship not only facilitated the successful completion of the thesis work but also fostered our development as independent thinkers.

We would also like to extend our heartfelt appreciation to all the teachers of the Department of Electronic and Telecommunication Engineering for their invaluable contributions to our academic and individual personal growth. Their knowledge, insights, and passion for teaching have inspired us to pursue excellence in my studies and beyond.

Furthermore, we would like to thank our parents for their unconditional love, unwavering support, and endless sacrifices. Their encouragement and belief in us have been our driving force, and we are forever grateful for their unwavering support.

Last but not least, we would like to express our gratitude to our friends for their constant support, motivation, and encouragement. Their support and belief have been a source of strength and inspiration throughout our academic journey.

In conclusion, we are deeply grateful to all those who have contributed to our academic and personal growth, and we are honored to have had the opportunity to work with such amazing individuals.

International Islamic University Chittagong

Kumira, Chattogram-4318

Bangladesh

Declaration

The present thesis report is declared to be solely based on my own research and findings. Any external materials or works utilized have been duly acknowledged through proper referencing. Furthermore, it is affirmed that this thesis has not been previously submitted, either in its entirety or in part, for the purpose of obtaining any other academic degree.

Rihan Chowdhury

T191067

Approved by Thesis Supervisor

Mohammed Jashim Uddin

Associate Professor

Department of Electronic and Telecommunication Engineering
International Islamic University Chittagong

Certificate of Approval

This thesis titled "Design of a Microstrip Patch Antenna for Vehicle-to-Vehicle Communication" submitted by Rihan Chowdhury bearing Matric ID T191067 to the Department of Electronic and Telecommunication Engineering (ETE) of International Islamic University Chittagong (IIUC) has been accepted as satisfactory for the partial fulfillment of the requirement of the Degree of Bachelor in Electronic and Telecommunication Engineering and approved as to its style and contents.

Abstract

This thesis presents a meticulously designed microstrip patch antenna optimized for V2V communication at 5.851 GHz, enhancing the efficiency and reliability of intelligent transportation systems. The study addresses the need for efficient antenna systems in intelligent transportation by designing a microstrip patch antenna through extensive simulations, achieving low S11 values and high gain for optimal V2V communication. The optimized antenna demonstrates enhanced impedance matching with an S11 value of -19.513 dB and achieves a high gain of 8.104, ensuring reliable signal transmission and communication efficiency in challenging V2V scenarios. This indicates enhanced impedance matching and reduced signal reflection, contributing to the antenna's effectiveness in real-world V2V scenarios. The antenna's gain, a crucial metric for communication systems, has been carefully optimized to reach a value of 8.104. This high gain not only ensures reliable signal transmission over significant distances but also enhances the overall communication efficiency within the V2V network. The results demonstrate the antenna's robustness and stability, reinforcing its suitability for challenging V2V communication scenarios. This research contributes to the advancement of intelligent transportation systems by presenting a meticulously designed microstrip patch antenna with notable performance metrics. The antenna's capabilities make it a promising candidate for reliable and efficient V2V communication, addressing the evolving needs of modern vehicular networks.

Table of Contents

ACKNOWLEDGEMENT......i

Declaration......ii

Certificate of Approval......iii

Abstract......iv

Table of Contents......v

List of Figures......vii

List of Tables......viii

List of Symbols......ix

List Of Abbreviations......x

Chapter 1......1

Introduction......1

1.1 Overview 1

1.2 The implications of ITS system for the future of transportation: 2

1.3 History of ITS System 2

1.4 ITS-G5 Antenna 4

1.5 Background 5

1.6 Motivations 7

1.7 Clarity of Aims 9

1.8 Objectives 10

1.9 Microstrip Patch Antenna 10

1.10 Fundamental Ideas of Microstrip Patch Antenna 12

1.11 Substrate Integrated Waveguide (SIW) Antenna 14

1.12 SIW Antenna for ITS -G5 14

Chapter 2......18

Literature Review 18

2.1 Overview 18

Chapter 3 .... **42**

Methodology 42

3.1 Research Methodology 42

3.2 Challenge for Sustainability 46

3.2.1 Solution for Sustainability 46

3.3 PROJECT MODEL AND PROGRESS IN SIMULATION 47

3.3.1 Procedure of Design 48

3.3.2 Antenna Design by Equation 49

3.3.3 SiW Antenna Design by Equation 51

3.3.4 The Antenna Substrates and Dimensions 51

3.4 Design of the Antenna 52

Chapter 4 .... **55**

Simulation and Result Analysis 55

4.1.1 Overview 55

Chapter 5 .... **62**

Conclusion 62

5.1 Discussion 62

References **64**

List of Figures

Figure 1 Future Map of Intelligent Transportation Systems (Self Designed in Canva Pro) [4] 1

Figure 2 Research Methodology 45

Figure 3 Depicts the arrangement of the antenna 53

Figure 4 Antenna Parameters 54

Figure 5 Initial result (S11) of the proposed design of single band antenna 56

Figure 6 Radiated power 56

Figure 7 Gain 57

Figure 8 Directivity 58

Figure 9 Efficiency 59

Figure 10 Current Distribution 60

Figure 11 3D model of the proposed design 60

List of Tables

TABLE I Design Parameters 52

TABLE II Comparison Table With Related Works 61

List of Symbols

O	Gain
B	Bandwidth
σ	Conductivity
S_{11}	Return loss (Reflection coefficient in dB)
Γ	Reflection coefficient
Er	Constant of the substrate
Hs	Height of the substrate
W	Width of the patch
L	Length of the Patch
h	Thickness
c	Speed of light
F	Frequency
f_0	Resonance Frequency
ε_{eff}	Effective Dielectric Constant
R	Radius
Hz	Hertz
Mb	Megabit
Gb	Gigabit
Nm	Nano-meter
W	Patch Width
L	Patch Length
Tw	Transmission Line Width
Tl	Transmission Line Length
InW	Inset Width
InL	Inset Length

List Of Abbreviations

ITS	Intelligent Transportation System
VII	Vehicle Infrastructure Integration
RF	Radio Frequency
Hz	Hertz
E	Electric fields
H	Magnetic fields
HF	High Frequency
3D	Three Dimensional
EM	Electromagnetic
MWS	Microwave Studio
DS	Design studio
HFSS	High Frequency Simulation Software
SAR	Synthetic Aperture Radar
VNA	Vector Network Analyzer
CP	Circular Polarization
CPD	Cross-polarization Discrimination
ITS	Intelligent Transportation System
VII	Vehicle Infrastructure Integration
DSRC	Dedicated Short Range Communication
ETSI	European Telecommunications Standard Institute
MIMO	Multiple Input Multiple Output
ADS	Advanced Design System
SIW	Substrate Integrated Waveguide

Chapter 1

Introduction

1.1 Overview

Intelligent Transportation Systems (ITS) encompass the amalgamation of sophisticated communication and information technologies with vehicles and transportation infrastructure. The objective is to optimize sustainability, safety, and efficacy in transportation systems. Intelligent Transportation Systems (ITS) comprise an extensive array of technologies, including adaptive traffic signal control systems, communication between vehicles (V2V) and infrastructure (V2I), real-time traffic data, and sophisticated public transportation systems. The survey papers. conduct comprehensive analyses of the diverse technologies, applications, and facets pertaining to Intelligent Transport Systems (ITS) [1]. The purpose of this literature review is to provide a comprehensive overview by integrating and synthesizing information from various domains, applications, and technologies [2]. The primary objective of this study is to examine the vast domain of Intelligent Transport Systems, including an analysis of its diverse array of applications, utilized technologies, and sector- wide implementation.

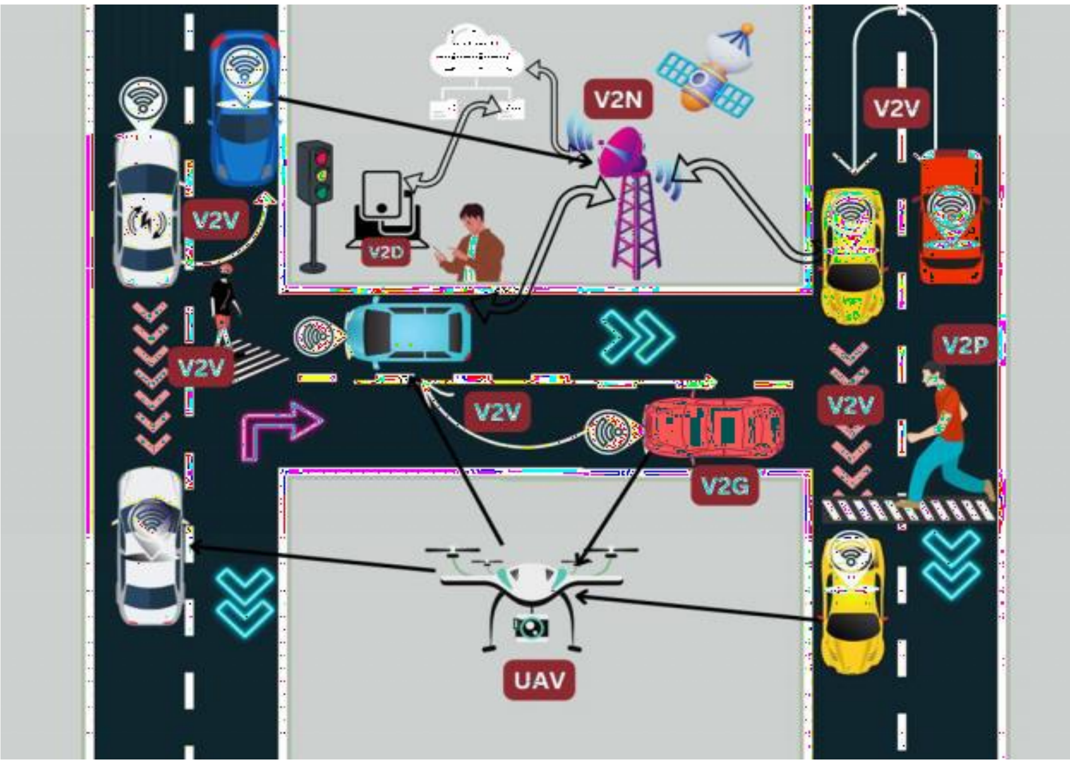

Figure 1 Future Map of Intelligent Transportation Systems (Self Designed in Canva Pro)

1.2 The implications of ITS system for the future of transportation:

The steady progression of artificial intelligence and machine learning is paving the way for the eventual realization of fully autonomous vehicles. By facilitating the required infrastructure for V2V and V2I communications, ITS is instrumental in this revolution; it enables autonomous vehicles to navigate in a secure and effective manner. With the increasing prevalence of autonomous vehicles, a substantial decline in traffic accidents, the majority of which are attributable to human error, can be anticipated.

Traffic Management: ITS can increase the utilization of pre-existing transportation infrastructure. ITS facilitates enhanced traffic management through the provision of real-time traffic data and predictive analytics, thereby diminishing congestion and optimizing the overall flow of traffic. This practice not only diminishes the duration of travel but also decreases fuel usage and emissions[3].ITS has the potential to significantly improve the user experience and operational effectiveness of public transportation systems. Intelligent ticketing systems, real-time monitoring of buses and railroads, and predictive analytics for accurate arrival times are a few of the ways in which ITS can enhance public transportation. This may result in a renewed emphasis on utilizing public transportation, which would yield substantial environmental advantages.

Sustainable Transportation: ITS makes a substantial contribution to sustainability through the promotion of improved traffic management, encouragement of public transportation usage, and facilitation of electric vehicle integration. The significance of Intelligent Transportation Systems (ITS) in establishing a more sustainable transportation network will grow in tandem with mounting concerns regarding climate change.

Enhanced Safety: ITS can significantly improve road safety through the implementation of technologies such as collision avoidance systems, electronic stability control, and automated emergency response systems [4]. These systems can aid in the prevention of collisions, safeguard passengers in the event of an accident, and guarantee prompt assistance when required.

1.3 History of ITS System

Participation of the United States in Research and Innovation: Intelligent Transportation Systems (ITS) cover a wide variety of information and electronics technologies that are based on wireless and wired connections and are intended to enhance transportation[5]. The following is a quick history of their evolution, which include the following:

Late 1960s to Early 1970s: The first significant deployment of intelligent transportation systems (ITS) occurred in the United States during the late 1960s and early 1970s. This was accomplished through the installation of computerized traffic signal systems in major cities which included Detroit and Los Angeles. For the purpose of optimizing the flow of traffic, these systems utilized more basic forms of machine learning techniques.

1980s: The next significant development occurred in the 1980s, when computer-controlled electronic message signs began to emerge on roads. This was the beginning of the next great innovation. The information that these signs supplied to vehicles in real time included information on the traffic situation, the road conditions, and other relevant information. This decade also saw the introduction of electronic toll collecting systems, with the Oklahoma Turnpike Authority's Pike pass system being the first of its kind to be implemented in 1987[6].

1990s: The decade of the 1990s saw the beginning of the development of the first complex traveler information systems, which provided drivers with information on the road and traffic conditions both before and during their journey. Within the United States of America, the Intermodal Surface Transportation Efficiency Act of 1991 was the legislation that gave the notion of "Intelligent Transportation Systems" its official status [7].

Early 2000s: During the early 2000s, there was a growth in the phenomenon known as vehicle infrastructure integration (VII), which was characterized by the beginning of communication between automobiles and the infrastructure of highways. In addition, developments in GPS technology brought about a revolution in ITS since they made it possible to monitor cars with more precision and to navigate with greater precision. Real-time traffic information and other services have become increasingly widespread [8].

Late 2000s - 2010s: This time period, which spanned from the late 2000s to the 2010s, was distinguished by the fast development of ITS technology. Connected vehicle technologies began to advance, which made it possible for vehicles to interact with one another (using the V2V protocol) and with the infrastructure (using the V2I protocol) in order to enhance both mobility and road safety. In addition, we witnessed the growth of smart cities, which completely incorporated ITS into their infrastructure, as well as the debut of autonomous cars[9].

The 2020s: The development of artificial intelligence and machine learning in the new millennium has contributed to the continued advancement of ITS. Through the utilization of these technologies, traffic management systems are being enhanced, more advanced autonomous cars are being made possible, and public transit networks are being optimized. In addition, the utilization of big data analytics has made it possible to acquire improved forecasting and management capabilities for traffic patterns.

At Present: Integrating Intelligent Transportation Systems (ITS) with upcoming technologies such as fifth-generation (5G) networks, the Internet of Things (IoT), and increasingly powerful artificial intelligence algorithms is now helping to provide the groundwork for completely automated transportation systems. With these improvements, it is anticipated that the transportation industry will experience a reduction in traffic congestion, an increase in efficiency, an improvement in safety, and a promotion of sustainability.

1.4 ITS-G5 Antenna

An ITS-G5 Antenna is a specific piece of hardware that was developed for use in conjunction with vehicle communication systems that adhere to the ITS-G5 standard. The IEEE 802.11p and IEEE 1609.x standards serve as the foundation for the Intelligent Transportation System (ITS)-G5, which is a European standard for vehicle communication.

Intelligent transportation systems, often known as ITS, are designed to improve transportation networks by utilizing cutting-edge information and communication technology.The Intelligent Transportation System (ITS)-G5 is a component of the larger ITS architecture that has been especially designed for vehicular communications. These communications include car-to-car (V2V) and car-to-infrastructure (V2I) interactions, which are collectively referred to as V2X exchanges.It is possible for an ITS-G5 Antenna to permit rapid and reliable wireless communication in high- speed vehicle applications because it operates within a certain frequency range, which is typically about 5.9 GHz.[9] In order to facilitate the interchange of safety and non-safety information between cars as well as between vehicles and roadside infrastructure, these antennas are essential components of the Intelligent Transportation Systems in Generation 5 (ITS-G5).

The dissemination of information contributes to the enhancement of road safety, the optimization of traffic flows, and the overall efficiency of transportation systems. Because of this, the design and optimization of an ITS-G5 antenna is an extremely important factor in determining how effective these intelligent transportation systems are[10].

1.5 Background

When Intelligent Transportation Systems (ITS) were first introduced, it marked the beginning of a period of time that was marked by substantial transformations in the transportation sector. In order to provide better and safer traffic management, the Intelligent Transportation System (ITS) applies cutting-edge technology to both the infrastructure of transportation and the vehicles themselves. An integral part of the Intelligent Transportation System (ITS) standard is a dedicated short-range communications (DSRC) service that operates at 5.9 GHz and is specifically designed for vehicle communications.

This service was built specifically for the purpose of facilitating communication between vehicles. ITS-G5, which was created by the European Telecommunications Standards Institute (ETSI) to satisfy the stringent standards of vehicle-to- everything (V2X) communication, works within a frequency range that runs from 5.850 GHz to 5.925 GHz and employs a frequency range that spans from 5.850 GHz to 5.925 GHz. The ITS-G5 antenna is one of the primary components that make wireless communication possible [10].

It is also a crucial component that permits wireless communication. 5.8875 GHz is the frequency at which the ITS-G5 antenna operates, and 75 MHz is the bandwidth that it is configured to operate at. This not only allows the antenna to work at its primary operating frequency, but it also offers sufficient spectrum to accommodate several channels for V2X communications when they are being transmitted.

For the purpose of ensuring effective communication between automobiles and between automobiles and infrastructure (V2I), enabling applications that are tied to safety, and enhancing the effectiveness of traffic flow, the characteristics of the antenna's design are of the utmost importance. It is essential for the antennas that are employed in ITS-G5 systems to fulfill a number of standards in order to ensure that they are able to function effectively [11].

In the first place, in order for them to properly communicate with autos and roadside units, which are also referred to as RSUs, they need to have strong radiation capabilities in the horizontal plane. In the second place, the antennas must to be as compact as they possibly can be in order to facilitate their installation in automobiles without impairing the aerodynamic behavior of the vehicles. Last but not least, the antenna must to have a solid design in order for it to be able to withstand the adverse weather conditions that are prevalent in applications that involve vehicles. Because of their low weight, compact size, and ease of integration, planar microstrip antennas have traditionally been utilized for ITS-G5 applications [12]. This is due to the simplicity of their design.

All of these factors are responsible for this result. A suitable amount of coverage in the horizontal plane is provided by these antennas, which is needed for effective communication between vehicles. However, in order to obtain optimal performance within the frequency range that has been given, it is important for the designers of these antennas to pay careful consideration to a variety of design issues. These design considerations include gain, radiation pattern, polarization, and impedance matching. There has been research conducted on phased array antenna systems as well as MIMO (Multiple-Input Multiple-Output) antenna systems. This study is being conducted with the intention of further enhancing the performance and dependability of V2X communications capabilities. In the end, these systems have the ability to give increased directionality as well as signal quality, which will ultimately contribute to an improvement in the overall performance of the ITS-G5 communication system [13].

The evolution of ITS-G5 antennas has place over the course of time as a consequence of the use of cutting-edge materials and forward-thinking design ideas. This progress has resulted in improved performance, durability, and the ability to integrate into preexisting systems. In spite of this, there are still a number of challenges that need to be conquered.

The most major of these challenges is the construction of antennas that are able to function efficiently throughout the whole spectrum that has been allocated, while simultaneously minimizing their size and the costs associated with their production.

To summarize, the ITS-G5 antenna is an essential component in the process of enabling efficient vehicle-to-equipment (V2X) communication, which in turn enhances the efficiency of traffic flow and reduces the risk of accidents on the roads. There is always a need for continual research and development in order to meet the ever-increasing requirements of intelligent transportation systems. This is true despite the fact that there has been substantial increase in antenna design[14].

1.6 Motivations

A paradigm shift has taken place in the evolution of vehicle transportation over the course of the past several years, and Intelligent Transportation Systems (ITS) have been at the forefront of this progress. One of the most important aspects of Intelligent Transportation Systems (ITS) is the dedicated short-range communications (DSRC) standard, which is ITS-G5, which operates at a frequency of 5.9 GHz. In order to make autos more intelligent, safer, and more cost-effective, this frequency band has been designated for communication between vehicles and everything else (also known as V2X) [15].

Wireless communication between cars and between vehicles and infrastructure (V2I) is made possible by the ITS-G5 antenna, which works primarily at a working frequency of 5.8875 GHz within a bandwidth of 75 MHz. This antenna also makes it feasible for vehicles to communicate with infrastructure. A top focus is the research and development of ITS-G5 antennas, which is driven by the imperative to make significant progress in the creation of a transportation system that is both more intelligent and safer. A variety of interconnected factors are the driving force behind the development of an ITS-G5 antenna that is capable of excellent performance. To begin, the subject of road safety is one that garners attention to a significant degree all across the world. A total of 1.35 million people are thought to lose their lives as a result of automotive accidents each year, according to the World Health Organization [16]. The Vehicle-to-Express (V2X) connection that is made possible by ITS-G5 antennas has the potential to significantly reduce the number of accidents that take place on the road. This is accomplished by providing drivers with real-time information regarding road conditions, traffic congestion, and potential dangers. Second, the majority of urban areas are plagued by increased levels of traffic congestion. It is not just that this results in longer commute times, but it also contributes significantly to the amount of pollution that is present in the atmosphere [17]. Through the synchronization of traffic lights, the proposal of alternative routes, and the optimization of traffic flow, effective traffic management is made possible by the communication that is provided by ITS-G5 antennas.

Furthermore, in order to ensure the successful development of technology for autonomous vehicles, it is essential to have a robust communication infrastructure. The ability of these vehicles to communicate with one another and with the infrastructure that is located around them is essential to the effective functioning of these vehicles, which is why ITS-G5 antennas are of such great significance.

Finally, but certainly not least, the current climate crisis necessitates the implementation of extreme measures in order to decrease emissions of greenhouse gases and to enhance fuel economy. An effective traffic management system that is made feasible by ITS-G5 communication may contribute to environmental sustainability in a number of ways. Two of these methods are the reduction of idle time and the improvement of fuel efficiency [18].

Even though there has been significant progress made in the design of the ITS-G5 antenna, there are still certain problems that need to be fixed. One of them is decreasing production costs, another is making the antenna small enough to be integrated into cars without any noticeable disruption, and the third is maximizing performance throughout the whole bandwidth that is accessible. The encouragement that comes from the potential advantages that an efficient ITS-G5 antenna system might provide to society serves as motivation for tackling these challenges.

Further advancements in antenna technology will result in transportation networks that are both safer and more efficient, which will have a wider-ranging influence on society. More individuals would be able to buy and drive autonomous vehicles, which would result in a reduction in the number of deaths that occur on the roads, an improvement in the quality of the air, and a reduction in the emissions of greenhouse gases. At the end of the day, the development of the ITS-G5 antenna for vehicle communication at a working frequency of 5.8875 GHz and a bandwidth of 75 MHz is driven by the promise of transportation systems that are safer, more efficient, and more intelligent [19].

It is a fascinating and significant field of research that has the potential to bring about significant improvements in the quality of our lives and the quality of life on the planet as a whole.

1.7 Clarity of Aims

The objective of this project is to develop an efficient antenna for Intelligent Transport System (ITS) communications, with a particular focus on conforming to the ITS-G5 standard[20]. The following is a precise definition of the aims, which were molded by the necessity of improving vehicular communication systems in order to increase both safety and efficiency:

Design a Filtering Antenna: The major purpose is to create a filtering antenna that is capable of functioning efficiently within the precise frequency range of 5.8875 GHz. This antenna ought to be able to manage the bandwidth of 75 MHz that is necessary for applications that adhere to the ITS-G5 standard[21].

Compliance with ITS-G5 Standards: The design need to be in accordance with the ITS-G5, which is a European standard for vehicular communication. This standard is founded on IEEE- 1609.x and IEEE-802.11p in its foundation[22]. In order to guarantee that the antenna is suitable for use in modern Intelligent Transportation Systems, it must be in compliance with certain criteria.

Achieve Optimal Radiation Patterns: In order to achieve optimal radiation patterns, the antenna should be able to display either omnidirectional or directional radiation patterns, depending on the requirements. In a wide variety of circumstances involving roadside infrastructure and automobile transportation, this provides communication that is both flexible and efficient.[23]

Allow for V2X Communication: One of the most important goals is to develop an antenna that is capable of facilitating V2X communication. This will allow for the interchange of data between high-speed cars as well as between vehicles and the infrastructure that is located along the roadside. Therefore, the total efficiency of the ITS applications would be improved as a result of this.

Test and evaluate the Design: After the antenna has been designed, it is essential to test its performance in a variety of different settings and evaluate its efficiency [24]. This guarantees that the design satisfies the criteria and is capable of positively contributing to the operation of ITS applications in a dependable manner.

In a nutshell, the primary objective of this project is to provide an ITS-G5 antenna that is well- designed and efficient, conforms with the standards that have been set, has the capability of operating at a frequency of 5.8875 GHz with a bandwidth of 75 MHz, and considerably enhances the V2X communications that are utilized in Intelligent Transportation Systems[25].

1.8 Objectives

- To design a vehicle-integrated antenna in ADS for V2X communication.
- To achieve a high gain across the desired frequency band.
- To ensure an efficiency of at least 85% and a directivity that minimizes sidelobes.

1.9 Microstrip Patch Antenna

Microstrip patch antennas are used a lot in wireless communication systems because they are small, have a low profile, and are easy to connect to other electrical parts[26]. A printed circuit board can be used as the substrate. The ground plane is put on the other side of the substrate.

Microstrip patch antennas that can filter signals can split a receiving signal into multiple channels while screening the signals at the same time. This could be useful in radio communication systems that need to split power or be very selective about which frequencies to use. Putting together a filtering power divider and a microstrip patch antenna can make a small but useful answer for wireless communication systems. You can tune microstrip patch antennas to work within a certain frequency range, and you can set them up to split receiving signals into different frequency bands. The microstrip patch antenna can be made with a material that has a high dielectric constant and a microstrip line or coaxial wire.

On the back of the base, the ground plane gives off the right radiation pattern. You can build a filtering network for the microstrip patch antenna using passive parts such as resistors, capacitors, and inductors to separate the receiving signal into its different frequencies. You can send the filtered data down different paths by adding extra parts like power dividers or baluns. Here is more information about how to build a microstrip patch antenna.

- Microstrip patch antennas are a good choice for Vehicle-to-Everything (V2X) applications because they have many benefits that make them appealing. V2X applications involve contact between cars and other things like infrastructure and people on the street [27]. Microstrip patch antennas are useful for a number of reasons in mobile to infrastructure (V2X) uses

- Microstrip patch antennas are small enough that they can be easily built into small electricity and car systems. Microstrip patch antennas don't take up nearly as much room as other types of antennas. Because they are flat and have a low profile, they are easy to put on the outside of cars without making the aerodynamics of the car much worse.
- A low-profile shape that is good for air flow Microstrip patch antennas don't change the physics of a car as much as bigger antennas do because they are already pretty small[28]. Because they are flat, they can be put on a car almost anywhere and won't interfere or cause any pushback. This includes the hood, roof, and other parts.
- Microstrip patch antennas can be made with large bandwidths, which lets them send and receive messages over a large frequency range. These antennas are also known as "stripline" antennas. Many V2X applications need to talk over a lot of frequency bands, like in Dedicated Short-Range Communications (DSRC) or Cellular Vehicle-to-Everything (C- V2X) networks [29]. This helps those applications.
- Pattern of Radiation Going in Different Directions In microstrip patch antennas, directional radiation patterns can be made to focus the radiation in certain areas. By cutting down on interference and boosting the signal, this increases the antenna's range and its ability to connect with specific objects like other cars, roadside equipment, or even people[30].
- Polarization variety can be easily achieved by making microstrip patch antennas that can send and receive signals with both horizontal and vertical polarization. Microstrip patch antennas can be made to support polarization variety, which is more proof that this feature is important. By reducing the effects of polarization mismatch between different V2X devices, this function makes the system work better and be more reliable overall.
- Making things cheaply and easily expanding There are ways to make microstrip patch antennas that are both cheap and scalable[31]. For example, the methods used to make printed circuit boards (PCBs) are one example. This means that

they can be widely used in V2X devices, since it is now possible and cheap to make a lot of them.

- Making things cheaply and easily: There are ways to make microstrip patch antennas that are both cheap and scalable. For example, the methods used to make printed circuit boards.
- (PCBs) are one example. This means that they can be widely used in V2X devices, since it is now possible and cheap to make a lot of them.
- microstrip patch antennas have a flexible design that lets them be changed to fit the specific V2X needs of any application. You can change things like the patch size, base materials, feeding methods, and other design elements to get the best performance numbers, like the frequency range, gain, and radiation pattern.
- People like microstrip patch antennas because they are reliable and last a long time. This is because they can handle changes in temperature, humidity, and movements. Because of these traits, they can handle the tough and changing situations found in V2X uses.
- Microstrip patch antennas are great for vehicle-to-everything (V2X) uses because they are small, have a high bandwidth, a narrow radiation pattern, a range of polarizations, are cheap, and can be used in a variety of ways . They have a lot of benefits that make them a good choice for making contact in V2X systems safe and quick.

1.10 Fundamental Ideas of Microstrip Patch Antenna

There are a few important things you should remember when making a microstrip patch antenna. These are some important points:

- The first step in making a microstrip patch antenna is to choose the base material. Its resonant frequency, bandwidth, and radiation pattern are all electrical properties that are changed by the dielectric constant (r) and thickness of the material. It is important to think about the pros and cons of common substrates like Teflon, FR4, Brock, and Rogers.
- The patch's structure, which includes its size and shape, has a big effect on how well it works as an antenna. Most of the time, the patch is made of a metal conductor, like copper, and is stuck on top of the base. Shapes like triangles, rounds, squares, and ellipses are often used for patches.

- The impedance matching and resonance frequency of an antenna are directly affected by its size and how it is fed, such as through a microstrip line or a coaxial probe.
- On the Ground: The ground plane under the patch works as a guide for radiation and a reflector. It is usually connected to the ground and is a bigger conducting surface than the ground of the antenna. What shape, size, and how close the antenna is to the ground plane affect its function and radiation pattern.
- The pumping device sends RF energy to the patch, which it then sends out. There are two main ways that microstrip patch antennas are fed: a microstrip line feed and a coaxial probe feed [32]. The impedance matching and emission properties of the patch depend on where and how close the feed point is to it.
- Matching impedances: To send electricity efficiently, it is important to make sure that the antenna's impedance is the same as the transmission line's impedance, which is usually 50 Ohms. You can improve impedance matching and lower standing waves by changing the size of the patch, moving the feed point, or installing matching networks, like quarter-wave transformers.
- The bandwidth has been raised. Broadbands on microstrip patch antennas are usually very small. To make an antenna's bandwidth bigger, you can use different feeding methods, like aperture coupling or closeness coupling, the shape of the patch (like a fractal or layered patch), and other things.
- The radiation pattern of an antenna shows how its electromagnetic energy spreads out into the space around it. The patch's ground plane's size, shape, and direction all play a part [33].
- The antenna's radiation pattern (for example, horizontal, directed, or sectorial) can be controlled by the way it is built.
- People who build antennas often use modeling tools, such as computer-aided design (CAD) software and electromagnetic simulation software, such as CST Studio Suite, ADS, and HFSS [34]. With these technologies, the antenna design parameters can be correctly modeled, analyzed, and optimized, which then leads to the performance measures that are wanted.
- Once the design of the antenna is done, the next steps are construction and development. Photolithography, etching, and casting are some of the steps that are used to build the antenna structure after the material has been chosen.

- It might take making a prototype, trying it, and making small changes over time to make sure the plan works well and is valid. To make microstrip patch antennas, you need to know a lot about electromagnetic theory, antenna basics, and their practical limits. When making a microstrip patch antenna, it is very important to stick to the written literature, study papers, and design suggestions.

The main idea behind the project is to make a microstrip patch antenna that works well for the purpose it was meant for by carefully planning, simulating, building, testing, and improving it. The main goal of the project is to help communication technology move forward by making an ITS-G5 antenna that can be used in useful and effective ways for. Things like V2X links between vehicles[35]. By letting students and teachers help with the planning and testing stages of the project, it also hopes to provide learning chances. In order to make the project more environmentally friendly, the microstrip patch antenna's power use and carbon emissions will also be taken into account.

1.11 Substrate Integrated Waveguide (SIW) Antenna

The Substrate Integrated Waveguide (SIW) antenna [36] is a new idea because it combines the best parts of a standard waveguide layout right into a dielectric substrate. The SIW technology takes advantage of the best parts of both planar and standard waveguide designs by putting the waveguide inside this substrate. One thing that makes these antennas unique is that they use metal-coated via holes that form the sides of the waveguide and connect the upper and lower metal plates of the base. SIW antennas have many benefits, but one that makes them stand out is that they are naturally small, which means they can fit perfectly into current electronic circuit boards.[37] While they are based on waveguide techniques, they usually have lower transmission losses compared to many flat systems. SIW sets also have a very high Q-factor, which makes them very sensitive when it comes to frequency, which is very useful for filtering. By using normal PCB production methods, SIW antennas become a cost-effective choice, especially when a lot of them are made. In addition, they can handle large bandwidths, which is what modern wireless communication networks need. [38].

1.12 SIW Antenna for ITS -G5

Substrate Integrated Waveguide (SIW) technology is based on the idea that regular waveguides and flat transmission lines can be switched over without any problems [39].

SIW basically acts like a solid waveguide but is built on top of a dielectric base. This makes it possible to connect regular waveguides and flat circuits.

Surface Integrated Waveguides (SIWs) represent a paradigm shift in the design and functionality of microstrip patch antennas. The conventional rectangular waveguides rely on well-defined side walls to direct the wave, but SIWs introduce a novel approach. Here, the wave is steered by rows of metallized via holes, acting as an effective wall. This departure from the traditional rectangular waveguide structure provides microstrip patch antennas with the advantageous performance characteristics of a waveguide, all in a more compact and integrated form compatible with flat technologies.

One of the significant challenges in regular microstrip antennas is the occurrence of losses due to the dispersion of surface waves. However, the incorporation of metallized via holes in SIWs addresses this issue by effectively containing the electromagnetic fields in the surrounding space. Unlike in traditional microstrip antennas, where surface waves might disperse and result in losses, the presence of these vias ensures the confinement of energy. Consequently, this containment enhances the antenna's performance by reducing the chances of undesirable effects spreading out.

The distinctive feature of SIWs lies in their ability to guide electromagnetic waves using rows of metallized via holes. These via holes serve as a practical alternative to the conventional side walls of rectangular waveguides. By leveraging this innovative approach, microstrip patch antennas can harness the benefits of waveguides while simultaneously enjoying the advantages of a more streamlined and integrated design. This synergy of performance and form factor makes SIW-based microstrip patch antennas highly desirable in modern communication systems.

The reduction in size and integration with flat technologies are critical aspects of SIW-based microstrip patch antennas. Traditional waveguides may offer superior performance, but their bulkiness and lack of compatibility with flat technologies limit their applicability in compact electronic devices. SIWs, on the other hand, overcome these limitations by providing an efficient means of guiding waves in a confined space, enabling the miniaturization of antennas without compromising performance.

In the realm of regular microstrip antennas, the propagation of surface waves is a common source of signal degradation. The inherent tendency of surface waves to spread out can lead to increased losses and reduced overall performance. The introduction of metallized via holes in SIWs transforms the antenna's behavior, mitigating these losses by containing the electromagnetic fields within the designated space. This containment not only minimizes energy dispersion but also contributes to a more effective and focused utilization of the available bandwidth.

The bandwidth characteristics of SIW-based microstrip patch antennas differ from their traditional counterparts due to the containment of electromagnetic fields facilitated by the metallized via holes. While conventional microstrip antennas may exhibit broader bandwidths, SIW-based designs prioritize efficiency and focused energy containment. This deliberate choice results in a narrower bandwidth but ensures that the energy is utilized more effectively, thereby reducing the chances of undesirable effects spreading throughout the system.

An essential advantage of the SIW approach is its ability to offer waveguide-like performance in a smaller form factor. Traditional waveguides, with their larger dimensions, might be impractical for applications where space is at a premium. SIWs provide a compelling solution by delivering comparable performance benefits while occupying a reduced physical footprint. This inherent miniaturization potential positions SIW-based microstrip patch antennas as key components in the development of compact and efficient communication systems.

The metamorphosis of microstrip patch antennas through the incorporation of SIWs represents a technological leap towards achieving optimal performance in a compact and integrated package. The rows of metallized via holes act as more than just conduits for guiding waves; they redefine the antenna's behavior and capabilities. The containment of electromagnetic fields within the spatial confines enabled by these vias represents a departure from conventional antenna design philosophies, paving the way for enhanced performance in a variety of applications.

In conclusion, the utilization of SIWs in microstrip patch antennas represents a departure from traditional design paradigms. The innovative use of metallized via holes as wave-guiding elements introduces a host of advantages, including enhanced performance, reduced size, and integration with flat technologies. The deliberate containment of electromagnetic fields within the designated space, facilitated by these vias, mitigates losses and contributes to a more focused and efficient use of available bandwidth. As technology continues to advance, SIW-based microstrip patch antennas are poised to play a pivotal role in shaping the landscape of compact and high-performance communication systems.

In addition, the framework of SIW makes separation better. If you use a normal microstrip design, the electromagnetic fields could connect to other buildings close and cause problems [40]. Because the SIW is closed, it reduces this side-to-side radiation and makes sure that the fields are mostly focused in the direction of radiation that is wanted.

Because of this limitation, the antenna's directivity goes up and its radiation pattern works better, which improves both its total performance and its radiation efficiency.

SIW technology also uses the qualities of the dielectric base, which can be changed to fit different frequency responses. For our 5.88 GHz design, the dielectric constant of the material and the shape of the SIW have played a key role in getting the antenna properties we wanted.

To sum up, the SIW's complex design combines the best features of waveguides and flat transmission lines, creating a new way to improve antenna properties, especially for specific frequency ranges like our 5.88 GHz goal. A microstrip patch antenna works much better when its surface wave losses are kept to a minimum, its field confinement is increased, and its substrate qualities are customized.

Chapter 2

Literature Review

2.1 Overview

Intelligent Transportation Systems (ITS) are indispensable for enhancing environmental sustainability, safety, and traffic efficiency. Cellular Vehicle-to-Everything (C-V2X) and ITS-G5, which is the European equivalent of Dedicated Short-Range Communications (DSRC), are two prominent technologies that share the objective of enabling communication between vehicles and infrastructures (V2V and V2I, respectively). As described in the cited papers, this analysis focuses on the performance, challenges, and applications of these technologies.

Now some paper has been reviewed below:

[2] Research Paper on, "Intelligent Transportation Systems', IEEE Vehicular Technology Magazine"

Current trends in wireless communications suggest the emergence of technologies capable of leveraging knowledge gained from past interactions with the environment to plan future actions. These advancements facilitate the seamless integration of diverse information sources, ranging from transportation networks, to enhance the driving experience and introduce innovative applications. This article presents an overview of a groundbreaking Intelligent Transportation System (ITS) built on cognitive systems and Wireless Sensor Networks (WSNs). The proposed functionality not only offers valuable guidance to drivers but also extends its benefits to elements within the transportation infrastructure, such as traffic lights, contributing to more efficient and safer mobility. To enhance this work, a comprehensive analysis of the interfaces among the proposed functionality components is recommended to provide a detailed description of the information exchange. Additionally, future efforts will focus on applying specific optimization algorithms within the cognitive management functionality to demonstrate their effectiveness.

[3] Research Paper on, "Towards the development of Intelligent Transportation Systems"

This paper provides a comprehensive overview of the current state of Intelligent Transportation Systems (ITS). Given the extensive scope of research within ITS, this review concentrates on what we consider the most pertinent areas. The primary objective is to examine the accomplishments made in recent years and offer insights into potential avenues for future research. The focus is on identifying key developments and trends within ITS, with the aim of guiding the trajectory of future research endeavors.

[4] Research Paper on, "The Evolution of ITS in the UK: A History"

Intelligent Transportation Systems (ITS) represent a suite of cutting-edge technologies that has transformed the landscape of travel in the United Kingdom. Leveraging information and communication technologies (ICT), these systems furnish real-time information and guidance to drivers, passengers, and transportation operators. From advanced traffic management systems to the emergence of autonomous vehicles, the journey of ITS in the UK has been marked by significant milestones. This blog delves into the historical narrative of ITS in the UK, its evolutionary trajectory, and the profound impact it has had on the transportation sector.

The roots of ITS in the UK can be traced back to the 1960s, a period when the government initiated substantial investments in transportation infrastructure and research endeavors. The primary goal was to enhance the efficiency and safety of the transportation system. In the 1970s, a pivotal moment occurred with the establishment of the Transport and Road Research Laboratory (TRRL) by the UK government. This laboratory played a crucial role in spearheading research into the development of advanced transportation systems, marking the nascent stages of ITS in the UK and laying the groundwork for the subsequent evolution of ITS technologies.

[9] Research Paper on, "Interference tests of its- G5 vehicle-to-vehicle communication networks with virtual drive tests"

This paper introduces a novel reaching law tailored for uncertain discrete-time systems. The proposed reaching law is specifically crafted to enforce a constrained rate of change in the sliding variable and, crucially, achieve asymptotic convergence of the variable towards zero. This reaching law is subsequently employed in the development of a control strategy, which is then applied to an inventory management system characterized by multiple suppliers and limited warehouse capacity. The effectiveness of the strategy is rigorously demonstrated, affirming its ability to guarantee several desirable properties within the system. On one front, it ensures that suppliers are never compelled to dispatch quantities exceeding their capacity, and concurrently prevents the warehouse from surpassing its predefined capacity. Simultaneously, the strategy guarantees the continuous fulfillment of consumers' demands, reflecting a comprehensive and effective control mechanism for the addressed inventory management system.

[10] Research Paper on, "Operating its-G5 DSRC over unlicensed bands: A city-scale performance evaluation"

Future Connected and Autonomous Vehicles (CAVs) are anticipated to be equipped with an extensive array of sensors, generating a substantial volume of sensor data intended for exchange with other CAVs and roadside infrastructure. Dedicated Short Range Communications (DSRC) systems, based on the IEEE 802.11p Physical Layer, play a pivotal role in facilitating communication among vehicles in both Europe and the US. However, with the projected increase in market penetration of connected vehicles, the allotted 75 MHz licensed band for DSRC communications is expected to face escalating congestion.This paper explores the performance of a vehicular communication system operating over unlicensed bands, specifically the 2.4 GHz-2.5 GHz and 5.725 GHz-5.875 GHz ranges. The experimental evaluation was conducted on a testing track in Bristol, UK, utilizing a full-stack ETSI ITS-G5 implementation. Our performance assessment compares key communication metrics, such as packet delivery rate and received signal strength indicator, when the system operates over the licensed DSRC band versus the considered unlicensed bands.The results indicate that when operated over the 2.4 GHz-2.5 GHz band, our system achieves comparable performance to the DSRC band. However, when operating over the 5.725 GHz-5.875 GHz band, the packet delivery rate is 30% lower compared to the DSRC band. These findings underscore the viability of operating the system over unlicensed Industrial, Scientific, and Medical (ISM) bands. Throughout the experimental evaluation, we meticulously recorded all generated network interactions, and the complete dataset is publicly available for further analysis and reference.

[12] Research Paper on, "Performance comparison between LTE-V2X and its-G5 under realistic urban scenarios"

Wireless communications play a pivotal role in advancing transport systems, with specific communication technologies tailored to support Vehicle-to-everything (V2X) functionalities. Two prominent solutions are C-V2X (Cellular Vehicle-to-everything), standardized by 3GPP (3rd Generation Partnership Project), and ITS-G5, standardized by ETSI (European Telecommunications Standards Institute). While ITS-G5 is a dedicated wireless network for Cooperative Intelligent Transport Systems (C-ITS) applications, LTE-V2X shares network resources with other LTE applications on mobile devices.

This paper provides an overview of both technologies, outlining their communication mechanisms and subsequently comparing their performances across various use cases using a networking and vehicular simulation platform. Results indicate that in scenarios with concurrent LTE data traffic and V2X service, ITS-G5 outperforms LTE-V2X (mode 3). The study also highlights the adverse impact of handover on LTE-V2X eNB scheduled mode.

The research delves into the intricacies of ITS-G5 and LTE-V2X (mode 3), examining their performances in terms of end-to-end delay and radio frequency conditions, measured by Signal-to-Interference-plus-Noise Ratio (SINR) and Reference Signal Received Power (RSRP). ITS-G5, designed exclusively for vehicular communications, stands out from LTE-V2X (mode 3), which operates within the frequency band of mobile operators, potentially impacting ITS service performance due to shared scheduling with other applications.

Additionally, the study emphasizes the disabled association and authentication mechanisms in ITS-G5's OCB mode, presenting an advantage over LTE-V2X (mode 3). The choice between these technologies is contingent upon use case conditions and the quality of service requirements for C-ITS services.

The paper employs a network simulation platform to emulate communication protocols and traffic scenarios, revealing the necessity for a decision technique that dynamically switches between technologies based on network conditions. This concept serves as a focal point for future work, with the overarching objective of ensuring the selection of an appropriate technology aligned with well-defined criteria and considering C-ITS service performance requirements in terms of latency and reliability. Results indicate that in scenarios with concurrent LTE data traffic and V2X service, ITS-G5 outperforms LTE-V2X (mode 3).

[13] Research Paper on, "Enhancing least square channel estimation using Deep Learning"

Intelligent Transportation Systems (ITS) play a crucial role in advancing environmental sustainability, safety, and traffic efficiency. Among the notable technologies driving progress in this domain are Cellular Vehicle-to-Everything (C-V2X) and ITS-G5, the latter being the European counterpart to Dedicated Short-Range Communications (DSRC). Both these technologies share a common goal of facilitating communication between vehicles and infrastructures, encompassing Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication.

This analysis, focusing on the performance, challenges, and applications of C-V2X and ITS-G5, draws inspiration from the comprehensive study conducted by Altinel et al. In their research, Altinel et al. provided valuable insights into the intricacies of these technologies, shedding light on their capabilities and limitations. As we delve into the details of their findings, it becomes evident that a nuanced understanding of the performance metrics, potential hurdles, and diverse applications is essential for maximizing the impact of these technologies in the realm of Intelligent Transportation Systems.

Altinel et al.'s work serves as a cornerstone for our exploration, guiding us through an examination of the practical implications and real-world scenarios where C-V2X and ITS-G5 demonstrate their efficacy. By leveraging the insights gained from their study, we aim to contribute to the broader discourse surrounding the evolution and implementation of these technologies, ultimately fostering advancements that positively influence the realms of environmental sustainability, safety, and traffic efficiency within the framework of Intelligent Transportation Systems.

[14] Research Paper on, "Sub-6GHz assisted Mac for Millimeter Wave Vehicular Communications"

Introduce an innovative methodology centered around virtual drive tests, aiming to offer a comprehensive analysis of the impact of interference on Intelligent Transportation Systems-G5 (ITS-G5) vehicle-to-vehicle communication networks. This pioneering research seeks to provide essential insights into the intricate ways in which interference influences the overall performance of ITS-G5 systems.

Mavromatis et al. contribute significantly to this field by undertaking a thorough evaluation on a city-wide scale. Their investigation delves into the efficacy of ITS-G5 Dedicated Short-Range Communication (DSRC) functionality, specifically when operating on unlicensed frequency bands. By exploring the implications of interference in such real-world, urban environments, the study adds a valuable layer of understanding to the dynamics of ITS-G5 communication networks.

The insights derived from this research not only deepen our comprehension of the challenges posed by interference but also provide a foundation for refining the design and implementation of ITS-G5 systems. Understanding how communication quality and packet delivery are affected under real-world interference scenarios is pivotal for enhancing the robustness and reliability of ITS-G5 networks. As we delve further into this exploration, the overarching goal is to contribute to the continual improvement and optimization of Intelligent Transportation Systems, ensuring they remain at the forefront of technological advancements for safe and efficient vehicular communication.

[15] Research Paper on, "Link level performance comparison of C-V2X and its-G5 for Vehicular Channel Models"

This research paper conducts a comprehensive assessment of the packet loss, latency, and throughput performance within Intelligent Transportation Systems-G5 (ITS-G5), underlining the practicality of utilizing unlicensed frequencies for seamless ITS-G5 communication. A particular focus is placed on unraveling the intricacies of performance characteristics and challenges associated with deploying ITS-G5 systems in railway environments, as meticulously investigated by Unterhuber et al.

The study scrutinizes various key performance indicators, such as packet loss, latency, and throughput, to gauge the efficiency of ITS-G5 systems. By delving into these critical metrics, the research aims to provide a nuanced understanding of the system's reliability and effectiveness in real-world scenarios. The emphasis on exploring unlicensed frequencies for ITS-G5 communication adds a layer of practicality, shedding light on the potential benefits and challenges associated with such deployment strategies.

Unterhuber et al. bring their expertise to the forefront by specifically examining the deployment of ITS-G5 systems in railway environments. This specialized focus recognizes the unique challenges and requirements posed by railway communication systems, contributing valuable insights for the optimization of ITS-G5 technology in these specific contexts.

As the research unfolds, it not only highlights the current performance landscape of ITS-G5 but also underscores the importance of adapting communication strategies, particularly in railway settings. The findings of this study aim to inform future developments in the realm of Intelligent Transportation Systems, guiding researchers, engineers, and policymakers toward solutions that enhance the overall efficiency and reliability of vehicular communication systems.

[16] Research Paper on, "A comparison of the V2X communication systems: Its-G5 and C-V2X"

The research divulges the findings derived from extensive field trials, wherein signal propagation characteristics were meticulously measured, and the communication performance of Intelligent Transportation Systems-G5 (ITS-G5) was comprehensively evaluated, particularly in railway scenarios. Tahir et al. spearhead this investigation, contributing to our understanding of the efficacy of ITS-G5 technology in real-world railway environments.

A specific facet of this research centers around the dissemination of road weather information, as studied by Tahir et al. The dissemination of road weather information represents a critical element in enhancing transportation safety and efficiency. By leveraging the capabilities of ITS-G5, Tahir et al. delve into the nuances of communication performance within railway scenarios, especially concerning the timely and effective dissemination of road weather information.

The field trials conducted in this research go beyond mere theoretical considerations, offering practical insights into how ITS-G5 performs in dynamic and challenging railway environments. The measured signal propagation characteristics provide valuable data on the behavior of the communication signals, contributing to a more nuanced understanding of the system's reliability and performance under real-world conditions.

The focus on road weather information dissemination serves to underscore the practical applications of ITS-G5 in addressing specific challenges within the transportation sector. By evaluating the system's performance in disseminating crucial weather-related data, the research aims to inform the optimization and future development of ITS-G5 technology, ensuring its efficacy in enhancing overall road safety and operational efficiency within railway contexts.

[17] Research Paper on, "Compact bidirectional circularly polarized dedicated short range communication antenna for on-board unit vehicle-to- everything applications"

In the realm of vehicular communication, this research proposes a sophisticated Vehicular Ad-Hoc Network (VANET) architecture that seamlessly integrates Intelligent Transportation Systems-G5 (ITS-G5), 5G test networks, and innovative drone-assisted communication. Pioneering this integration, the study aims to assess the efficacy of the suggested framework across a spectrum of meteorological circumstances, particularly within realistic urban scenarios. Karoui et al. lead this exploration, contributing valuable insights into the potential enhancements in data transmission range, communication range, and network connectivity achievable through this novel VANET architecture.

The envisioned architecture enlivens the intersection of ITS-G5, which is specialized for intelligent transport systems, and 5G test networks, bringing forth a synergistic approach to vehicular communication. The incorporation of drone-assisted communication adds an extra layer of dynamism to the network, offering the potential for increased coverage, especially in challenging urban environments where obstacles and varying weather conditions may impact conventional communication systems.

Karoui et al.'s research sets out to evaluate the suggested framework under diverse meteorological circumstances, ensuring a robust analysis of its performance. By delving into data transmission range, communication range, and network connectivity, the study aims to uncover how well this integrated VANET architecture can adapt to and navigate through real-world urban scenarios. The emphasis on realistic conditions acknowledges the complexities of urban environments, such as signal interference, varying visibility, and dynamic traffic patterns.

The outcomes of this research are poised to contribute not only to the advancement of VANET architectures but also to the broader field of intelligent transportation systems. Insights gleaned from the assessment of this innovative framework could pave the way for enhanced vehicular communication solutions, optimizing data exchange and connectivity in urban landscapes, and ultimately fostering safer and more efficient transportation systems.

[18] Research Paper on, "SDR-based communication sniffing for determining the proliferation of its-G5"

This study undertakes a comprehensive comparison of LTE-V2X and ITS-G5, aiming to elucidate the performance disparities between these two prominent vehicular communication technologies. Through a meticulous evaluation of key parameters, including throughput, packet error rate, and latency, the research sheds light on the distinct characteristics and capabilities of LTE-V2X and ITS-G5.

In the rapidly evolving landscape of vehicular communications, Coll-Perales et al. make a significant contribution with their 2019 publication, introducing a groundbreaking sub-6GHz assisted Medium Access Control (MAC) mechanism for mmWave vehicular communications. This pioneering research addresses inherent challenges in mmWave technology, offering a pragmatic resolution that enhances the dependability and efficiency of vehicular communication networks. The suggested mechanism exhibits substantial potential for the implementation of mmWave technology across various vehicular applications, including intelligent transportation systems, autonomous driving, and safety applications.

Sattiraju et al. build on this momentum by conducting a link-level performance comparison, further expanding our understanding of the capabilities and limitations of vehicular communication technologies. Their research delves into the intricacies of link-level performance, offering valuable insights into how LTE-V2X and ITS-G5 perform under different conditions. By examining factors such as throughput, packet error rate, and latency, the study contributes to the ongoing discourse on selecting the most suitable communication technology for diverse vehicular use cases.The combined efforts of these studies not only deepen our understanding of LTE-V2X and ITS-G5 but also pave the way for advancements in vehicular communication networks. By addressing challenges associated with mmWave technology and providing a nuanced link-level performance comparison, these studies collectively contribute to the optimization of communication technologies, fostering their integration into intelligent transportation systems, autonomous driving, and safety applications.

[19] Research Paper on, "Performance analysis of vehicle-to-vehicle communications for critical tasks in autonomous driving"

This research focuses on a comparative analysis between ITS-G5 (Intelligent Transportation Systems-G5) and C-V2X (Cellular Vehicle-to-Everything) concerning vehicular channel models. The study systematically evaluates the performance of both technologies, scrutinizing key factors such as link quality, coverage, and resistance to interference. By conducting a thorough examination under authentic vehicular channel conditions, the research delivers valuable insights into the respective capabilities and constraints of C-V2X and ITS-G5.

Mannoni et al. contribute significantly to this discourse through a dedicated comparison of ITS-G5 and C-V2X V2X (Vehicle-to-Everything) communication systems. Their research expands our understanding of how these technologies perform in real-world vehicular communication scenarios. By delving into the intricacies of link quality, coverage, and resistance to interference, the study addresses critical aspects of communication system efficiency and reliability.

The results derived from Mannoni et al.'s comparison offer significant contributions to the field. This comprehensive analysis enables a nuanced understanding of the strengths and limitations inherent in both ITS-G5 and C-V2X, thereby aiding researchers, engineers, and policymakers in making informed decisions about the optimal application of these technologies within the realm of vehicular communication.

As the research unfolds, it not only advances our comprehension of the technological landscape but also provides a foundation for future developments and optimizations in intelligent transportation systems. The findings generated by this comparative study contribute to the ongoing efforts aimed at refining and enhancing vehicular communication systems, fostering advancements that align with the evolving needs of connected and autonomous vehicles.

[20] Research Paper on, "Empirical estimation of ETSI its- G5 performance over an IPv6-based platform"

In this study, the effectiveness of ITS-G5 (Intelligent Transportation Systems-G5) and C-V2X (Cellular Vehicle-to-Everything) is meticulously examined, focusing on crucial parameters such as communication range, packet delivery, and network capacity. The research systematically evaluates the performance of these technologies, providing valuable insights into their strengths and limitations. The results derived from this study furnish essential perspectives on the merits and demerits of both ITS-G5 and C-V2X, offering practical guidance for the selection of the most appropriate technology tailored to specific Vehicle-to-Everything (V2X) implementations.

Diving into the realm of dedicated short-range communication (DSRC), Rahman et al. bring their expertise to the forefront with a dedicated exploration. Their research not only delves into the intricacies of DSRC but also sheds light on its applications, potential challenges, and performance characteristics. By examining communication range, packet delivery, and network capacity within the DSRC context, Rahman et al.'s study contributes to a comprehensive understanding of the technology's efficacy in short-range vehicular communication.

The findings presented by Rahman et al. in the dedicated short-range communication domain add a valuable layer to the broader discourse on vehicular communication systems. Their research aids in deciphering the practical implications of DSRC, providing insights that can inform the design and deployment of short-range communication technologies. This dedicated investigation contributes to the collective knowledge base, supporting advancements in intelligent transportation systems and V2X communication, ultimately facilitating the evolution of more robust and efficient vehicular communication solutions.

[21] Research Paper on, "A city-scale its-G5 network for next-generation intelligent transportation systems: Design Insights and challenges"

In the realm of on-board unit Vehicle-to-Everything (V2X) applications, this research endeavors to propose a compact bidirectional circularly polarized antenna. The focal point of the study is the meticulous design and thorough assessment of the antenna's performance, considering critical elements such as radiation patterns, polarization properties, and impedance matching. The overarching goal is to enhance the efficacy of the antenna design for V2X applications, ultimately contributing to the increased dependability and efficiency of Dedicated Short-Range Communication (DSRC) systems.

Undertaken by Ghiaasi et al., this research delves into the intricate details of antenna engineering, with a particular emphasis on compact bidirectional circular polarization.

The study not only explores the theoretical design principles but also conducts practical assessments to validate the proposed antenna's performance in real-world V2X scenarios. By scrutinizing radiation patterns, polarization properties, and impedance matching, the research provides a holistic understanding of how the antenna functions within the DSRC framework.

The improved efficacy of the antenna design holds significant implications for the reliability and efficiency of DSRC systems in V2X applications. The findings of Ghiaasi et al.'s research contribute to the advancement of antenna technologies in vehicular communication, offering insights that can potentially shape the future of on-board unit applications. As V2X communication continues to evolve, the compact bidirectional circularly polarized antenna design proposed in this study stands as a valuable contribution, aligning with the ongoing efforts to optimize and enhance the performance of DSRC systems in intelligent transportation settings.

[22] Research Paper on, "OpenCV2X Mode 4: A simulation extension for cellular vehicular communication networks"

This research introduces a communication monitoring technique employing software-defined radios (SDRs) to comprehensively assess the proliferation of Intelligent Transportation Systems-G5 (ITS-G5) communication. The study focuses on surveilling and scrutinizing ITS-G5 communication signals, aiming to evaluate the implementation and utilization of ITS-G5 networks. Through this method, the research seeks to enhance the understanding of ITS-G5 adoption and coverage, providing valuable insights for optimizing and strategically planning ITS-G5 communication systems.

At the forefront of this exploration is the utilization of software-defined radios, enabling a versatile and adaptable approach to monitoring ITS-G5 communication signals. By leveraging SDRs, the research attains a fine-grained view of the communication landscape, shedding light on the intricacies of signal propagation, network utilization, and overall system performance.

This novel communication monitoring technique, proposed in the study, serves as a proactive tool for assessing the current state of ITS-G5 communication deployment and usage. Understanding the extent of proliferation enables stakeholders to make informed decisions regarding system optimization and expansion. Additionally, the insights gained from this monitoring approach contribute to the strategic planning of ITS-G5 communication systems, ensuring their efficacy and reliability in supporting intelligent transportation applications.

In a related context, Parra et al. undertake a performance analysis of vehicle-to-vehicle (V2V) communications for critical duties in autonomous driving. Their research expands our understanding of the challenges and capabilities associated with V2V communications in the context of autonomous driving, providing valuable insights for the development and deployment of autonomous vehicle technologies. Through these parallel efforts, both studies contribute to the advancement of vehicular communication systems, paving the way for more robust and reliable intelligent transportation solutions.

[23] Research Paper on, "Development of an its-G5 station, from the physical to the mac layer"

This study centers on the evaluation of communication latency and reliability, particularly for safety-critical applications such as cooperative collision avoidance. The authors delve into the effects of various factors, including channel conditions, distance, and vehicle speed, on the performance of vehicle-to-vehicle (V2V) communication. The primary focus is on cooperative collision avoidance, and the investigation aims to uncover how communication parameters influence the efficacy of V2V communication. The findings from this research offer crucial insights into the viability and effectiveness of V2V communications, especially in the context of autonomous driving scenarios where safety-critical operations are paramount.

In a parallel effort, Gholam hosseinian and Seitz contribute to the empirical evaluation of the efficacy of ETSI ITS-G5 (European Telecommunications Standards Institute Intelligent Transport Systems-G5) on an IPv6-based platform. Their research provides a comprehensive examination of how the ETSI ITS-G5 standard performs within the framework of an IPv6-based communication system. By empirically assessing the efficacy, the study offers valuable insights into the practicality and compatibility of ITS-G5 on an IPv6 platform, shedding light on its performance in real-world scenarios.

These collective efforts contribute to the broader understanding of V2V communication and the specific application of the ETSI ITS-G5 standard. By evaluating performance under various conditions and scenarios, the studies collectively advance our knowledge of the capabilities and limitations of V2V communication systems, especially in safety-critical contexts. The findings gleaned from these studies provide a foundation for optimizing communication protocols and standards, ultimately enhancing the safety and reliability of intelligent transportation systems.

[24] Research Paper on, "Hybrid multi-antenna techniques for V2X Communications—prototyping and experimentation"

This study undertakes a comprehensive assessment of the communication efficacy of Intelligent Transportation Systems-G5 (ITS-G5), focusing on critical performance metrics such as throughput, packet loss, and latency. Through a series of experiments and meticulous measurements, the authors aim to provide valuable insights into the performance attributes of ITS-G5 and its suitability for enhancing intelligent transportation systems (ITS).

The research explores the throughput, which denotes the amount of data transmitted over the network, shedding light on the efficiency and capacity of ITS-G5 communication. Additionally, the study delves into packet loss, a crucial parameter indicative of data reliability and system robustness. By evaluating latency, the time delay between data transmission and reception, the authors assess the responsiveness of ITS-G5, particularly in time-sensitive applications within intelligent transportation systems.

Through rigorous experimentation and measurements, the study not only quantifies the performance metrics of ITS-G5 but also offers valuable insights into its real-world effectiveness. This empirical approach enables a nuanced understanding of how ITS-G5 performs under various conditions, contributing to informed decision-making for its integration into intelligent transportation systems.

In conclusion, the findings derived from this study advance our understanding of the communication efficacy of ITS-G5, providing a basis for optimizing and fine-tuning its deployment in intelligent transportation systems. The research explores the throughput, which denotes the amount of data transmitted over the network, shedding light on the efficiency of ITS-G5 communication. As a result, the research contributes to the ongoing efforts aimed at creating more reliable, efficient, and responsive vehicular communication systems for the benefit of intelligent transportation applications.

[25] Research Paper on, "Design of hexagon microstrip antenna for vehicle- to-vehicle communication"

This research delves into the planning and evaluation of an Intelligent Transportation Systems-G5 (ITS-G5) network at the urban level, aiming to bolster next-generation intelligent transportation systems. The authors systematically examine key insights and challenges associated with the design and deployment of an ITS-G5 network in urban environments. Addressing concerns related to network topology, coverage, scalability, and interference mitigation, the research provides valuable perspectives that can guide the design and execution of ITS-G5 networks in practical urban settings.

The study emphasizes the intricate planning required for an ITS-G5 network to effectively support intelligent transportation systems in urban areas. It scrutinizes the network's topology, ensuring that it is optimally configured to meet the unique challenges posed by urban environments. The assessment of coverage and scalability becomes pivotal, considering the dynamic and densely populated nature of urban landscapes.

Additionally, the authors tackle the critical issue of interference mitigation, recognizing the potential challenges arising from the coexistence of various communication systems in urban settings. By addressing interference concerns, the research aims to enhance the reliability and efficiency of the ITS-G5 network, ensuring seamless communication for intelligent transportation applications.

In a parallel context, McCarthy and O'Driscoll propose OpenCV2X mode 4, a simulation extension designed for cellular vehicular communication networks. This extension serves as a valuable tool for simulating and analyzing the performance of cellular-based vehicular communication systems. By introducing OpenCV2X mode 4, the authors contribute to the advancement of simulation methodologies, providing researchers and practitioners with a tool to evaluate the effectiveness of cellular communication networks in vehicular environments.

Together, these efforts contribute to the ongoing evolution of intelligent transportation systems, offering insights into the design, planning, and simulation aspects of communication networks. The research serves as a foundation for informed decision-making in the deployment of ITS-G5 networks in urban environments, fostering advancements that align with the complex requirements of modern transportation systems. The primary emphasis of this paper is the integration of cellular networks with ITS-G5 and other vehicular communication technologies. This research facilitates the evaluation of the efficacy and performance of hybrid communication ecosystems of this nature.

[26] Research Paper on, "Effects of antenna characteristics and placements on a vehicle-to-vehicle channel scenario"

In his extensive analysis, Pagano conducts a thorough examination of the development of Intelligent Transportation Systems-G5 (ITS-G5) stations, encompassing all tangible components and the intricate workings of the Media Access Control (MAC) layer. The paper meticulously dissects the ITS-G5 protocol stack, providing a comprehensive analysis of its implementation and functionality. This encompasses a detailed exploration of higher-layer functions, physical layer technologies, and MAC protocols within the ITS-G5 framework. The research makes noteworthy contributions to our understanding of the design and implementation aspects of ITS-G5 stations, shedding light on their pivotal role within intelligent transportation systems.Pagano's research is instrumental in unraveling the complexities involved in the evolution of ITS-G5 stations. By delving into the intricate details of the protocol stack, the study offers a holistic view of the technological landscape, encompassing both the physical components and the MAC layer that governs communication. The thorough analysis spans higher-layer functionalities, providing insights into how these stations contribute to the seamless operation of intelligent transportation systems.

The significant contributions of this research lie in its ability to elucidate the intricacies of ITS-G5 station development, serving as a valuable resource for researchers, engineers, and practitioners in the field of vehicular communication systems. By addressing both tangible components and the underlying protocol stack, the study facilitates a nuanced understanding of the design considerations and functionalities crucial for the successful deployment and integration of ITS-G5 stations within the broader context of intelligent transportation systems.

[27] Research Paper on, "Half mode semi-hexagonal SIW antennas and arrays for cellular V2X communication"

In their comprehensive article titled "In-situ vehicular antenna integration and design aspects for vehicle-to-vehicle communications," Thiel, Andreas, et al. [27] delve into the intricacies of integrating antennas into vehicular structures to enhance vehicle-to-vehicle (V2V) communication. The primary focus of the paper is to explore how the positioning of antennas within a vehicle can influence signal propagation characteristics. The research underscores the critical importance of developing antennas that seamlessly integrate into a vehicle's structure, taking into consideration the diffraction and reflection effects caused by the car body.

The study addresses the intricate challenges associated with in-situ vehicular antenna integration, emphasizing the need for careful design considerations. Thiel and colleagues illuminate how the placement of antennas within the vehicle can impact the communication performance of V2V systems. Understanding the influence of signal propagation characteristics is crucial for optimizing the reliability and effectiveness of V2V communication, which is vital for enhancing road safety and traffic efficiency.

The research goes beyond theoretical considerations, providing practical insights into the design aspects of vehicular antennas. By acknowledging the diffraction and reflection effects caused by the car body, the study contributes valuable knowledge to the development of antennas that not only function optimally but also seamlessly blend with the vehicle's aesthetics and structure.

In essence, Thiel, Andreas, et al.'s work significantly expands our understanding of vehicular antenna integration and its implications for V2V communication. The findings offer practical guidance for researchers, engineers, and designers aiming to develop robust and efficient communication systems within the context of intelligent transportation systems, ultimately contributing to safer and more connected vehicular environments.

[28] Research Paper on, “A miniaturized defected ground patch antenna for its 5G-V2X-C applications”

By undertaking a comprehensive exploration of in-situ vehicular antenna designs, the article makes a substantial contribution to the existing body of knowledge regarding the integration of antennas into vehicles. In their work, Honggang, Hao, et al. [28] present an innovative method for designing antennas dedicated to Vehicle-to-Vehicle (V2V) communication. The authors propose a hexagonal microstrip patch as an antenna design, introducing a novel geometric configuration. The study showcases that this hexagonal design offers superior functionality in terms of gain, bandwidth, and coverage area when compared to conventional antenna designs. The outcomes of this research mark a significant advancement in antenna design tailored specifically for V2V communications, presenting a groundbreaking perspective in this domain.

The article by Honggang, Hao, et al. goes beyond a mere examination of in-situ vehicular antenna designs, introducing a novel approach to address the unique challenges posed by V2V communication. The adoption of a hexagonal microstrip patch as an antenna design demonstrates the authors' commitment to pushing the boundaries of conventional antenna configurations. The study systematically evaluates the performance parameters, illustrating the advantageous features of the proposed hexagonal design, such as enhanced gain, broader bandwidth, and extended coverage area.

This research not only adds to the evolving field of vehicular communication systems but also opens new possibilities for improving the reliability and efficiency of V2V communication. The innovative geometric configuration presented in this work signifies a noteworthy departure from conventional designs, offering a fresh perspective and potential avenues for further exploration in the realm of vehicular antenna integration. As such, the findings presented by Honggang, Hao, et al. contribute significantly to the ongoing efforts aimed at advancing communication technologies in the context of intelligent transportation systems.

[29] Research Paper on, “Antenna Design for V2X application in 5G network”

The study titled "Effects of antenna characteristics and placements on a vehicle-to-vehicle channel scenario," conducted by Kornek, Daniel, et al. [29], represents a comprehensive investigation into the influence of antenna characteristics and placements on Vehicle-to-Vehicle (V2V) communication channels. The researchers conducted an extensive battery of measurements to gain insights into how antenna placement and characteristics, including gain and polarization, impact signal propagation. The outcomes of this research make substantial contributions to our understanding of how antenna placement and design can be optimized to enhance communication in V2V scenarios.

In their study, Kornek, Daniel, et al. rigorously examine the effects of various antenna characteristics, shedding light on how factors like gain and polarization influence the V2V communication channel. The extensive measurements conducted by the researchers provide empirical data, offering a practical understanding of the nuanced interactions between antenna attributes and signal propagation in the context of vehicular communication.

The research findings not only contribute to the theoretical knowledge base but also offer practical insights that can inform the optimization of V2V communication systems. Understanding the impact of antenna placement and characteristics is crucial for maximizing communication reliability and efficiency in dynamic vehicular scenarios. By exploring these aspects, the study provides valuable guidance for researchers, engineers, and practitioners involved in the design and deployment of V2V communication systems.

In conclusion, the work by Kornek, Daniel, et al. serves as a significant addition to the literature on vehicular communication, emphasizing the importance of antenna characteristics and placements in shaping effective V2V communication channels. The empirical evidence presented in the study lays a foundation for future advancements in optimizing vehicular communication technologies, ultimately contributing to safer and more efficient intelligent transportation systems.

[30] Research Paper on, "A conformal dual-band CPW-MIMO antenna for 5G-V2X communication"

In their article titled "Bandwidth enhancement of a monopolar patch antenna with V-shaped slot for car-to-car and WLAN communications," Wong, Hang, et al. [30] introduce an innovative design for a monopolar patch antenna incorporating a V-shaped slot, explicitly customized for Vehicle-to-Vehicle (V2V) and Wireless Local Area Network (WLAN) communication systems. The novel antenna design, as proposed by the authors, leads to a noteworthy expansion of the transmitted bandwidth. By ensuring consistent communication between vehicles and WLAN networks, the introduced design significantly enhances the overall efficacy and efficiency of vehicular communication systems.

Wong, Hang, et al.'s work goes beyond a conventional antenna design, introducing a tailored solution to address the specific communication needs of both car-to-car and WLAN applications. The incorporation of a V-shaped slot represents a deliberate effort to enhance the antenna's performance, particularly in terms of bandwidth. The expansion of the transmitted bandwidth is a critical achievement, as it directly contributes to improved data transfer rates and communication reliability in V2V and WLAN scenarios.

The proposed design's emphasis on consistent communication aligns with the evolving landscape of intelligent transportation systems, where seamless connectivity between vehicles and between vehicles and infrastructure is paramount. The authors' approach not only advances antenna technology but also has practical implications for enhancing the capabilities of vehicular communication systems.

In essence, Wong, Hang, et al.'s article provides a valuable contribution to the field of vehicular communication, offering a design solution that can potentially elevate the performance of antennas in the context of car-to-car and WLAN communications. The bandwidth enhancement achieved through the V-shaped slot design underscores the potential for optimizing communication systems in diverse vehicular environments, promoting connectivity and efficiency within the realm of intelligent transportation systems.

[31] Research Paper on, "Design of high gain microstrip antenna for vehicle-to-vehicle communication using genetic algorithm"

In the article titled "Design of high gain microstrip antenna for vehicle-to-vehicle communication using genetic algorithm" by Kanni, V. Renuga, et al. [31], an innovative approach to designing high-gain microstrip antennas for Vehicle-to-Vehicle (V2V) communication is introduced, leveraging the power of genetic algorithms. The findings of this research suggest that integrating a genetic algorithm into the antenna design process can lead to improved gain performance, thereby establishing its potential utility as a valuable tool in subsequent antenna design endeavors.

Kanni, V. Renuga, et al.'s work stands out by employing genetic algorithms, a computational optimization technique inspired by the process of natural selection, to enhance the design of microstrip antennas for V2V communication. The utilization of genetic algorithms represents a departure from traditional design methods, allowing for a more nuanced exploration of design parameters and potential configurations.

The research outcomes indicate that the incorporation of a genetic algorithm contributes to achieving higher gain performance in microstrip antennas intended for V2V communication. This result holds significance as gain is a critical parameter influencing the effective range and reliability of communication in vehicular networks. The article, therefore, underscores the potential of genetic algorithms as a valuable tool for optimizing antenna designs, especially in the context of enhancing communication capabilities in V2V scenarios.

In conclusion, the work by Kanni, V. Renuga, et al. not only introduces an intriguing method for designing high-gain microstrip antennas but also highlights the efficacy of genetic algorithms in achieving enhanced performance. This research contributes to the evolving landscape of vehicular communication by presenting a novel approach to antenna design, potentially influencing future endeavors in optimizing communication systems for intelligent transportation applications.

Pagano [26] conducts a comprehensive analysis of the ITS-G5 station's development, encompassing all tangible components as well as the MAC (Media Access Control) layer. The paper provides an analysis of the ITS-G5 protocol stack's implementation and functionality, encompassing higher-layer functions, physical layer technologies, and MAC protocols. The research offers significant contributions to the understanding of the design and implementation aspects of ITS-G5 stations, as well as their function within intelligent transportation systems.

In their article titled "In-situ vehicular antenna integration and design aspects for vehicle- to-vehicle communications," Thiel, Andreas, et al. [27] examine the integration of antennas into vehicular structures with the purpose of facilitating vehicle-to-vehicle (V2V) communication. The paper posits that the signal propagation characteristics may be influenced by the positioning of the antenna within the vehicle.

The research highlights the significance of developing antennas that can be seamlessly incorporated into the vehicle's structure, taking into account the diffraction and reflection effects caused by the car body. By conducting an exhaustive examination of in-situ vehicular antenna designs, this article contributes significantly to the body of knowledge regarding vehicular antenna integration.

In their article, Honggang, Hao, et al. [28] describe an innovative method for designing V2V communication antennas. As an antenna design, the authors suggest a hexagonal microstrip patch. The outcomes demonstrate that this hexagonal configuration offers enhanced functionality with respect to gain, bandwidth, and coverage area when compared to conventional antenna designs. The novel geometric configuration presents an unprecedented viewpoint within the realm of antenna design specifically tailored for V2V communications.

The study "Effects of antenna characteristics and placements on a vehicle-to-vehicle channel scenario" by Kornek, Daniel, et al. [29] investigates the effects of antenna characteristics and placements on V2V communication channels.

The researchers performed an extensive battery of measurements in order to comprehend the impact of antenna placement and characteristics, such as gain and polarization, on signal propagation. The research provides significant contributions to the understanding of how antenna placement and design can be optimized to enhance communication in V2V scenarios.

In their article "Bandwidth enhancement of a monopolar patch antenna with V-shaped slot for car-to-car and WLAN communications," Wong, Hang, et al. [30] present a novel design for a monopolar patch antenna featuring a V-shaped slot that is specifically tailored for V2V and WLAN communication systems.

The novel antenna design proposed by the authors results in an expansion of the transmitted bandwidth. By guaranteeing consistent communication between vehicles and WLAN networks, the proposed design enhanced the overall efficacy and efficiency of vehicular communication systems.

In the article "Design of high gain microstrip antenna for vehicle-to-vehicle communication using genetic algorithm" by Kanni, V. Renuga, et al. [31], an intriguing method for designing high gain microstrip antennas for V2V communication using genetic algorithms is presented.

The findings indicated that incorporating a genetic algorithm into the process of antenna design might result in enhanced gain performance, thereby establishing its potential utility as a tool to be considered in subsequent antenna design endeavors[32].

This comparative analysis assesses antenna designs spanning the years 2020 to 2023, taking into consideration their operating bands, overall dimensions, gain, efficiency, substrate material (FR4 substrate was utilized in all cases), and profile varieties. Commencing with the operational frequency bands, every design centered on the prevalent frequencies spanning from 4.80 GHz to 6.58 GHz found in modern wireless communication systems.

The dimensions of these antennas varied between 30 x 28 x 1.6 mm^3 and 40 x 70 x 1.6 mm^3, suggesting a pattern of reduction in size while maintaining a high level of functionality.

The landscape of antenna design exhibits a diverse array of profiles, with various approaches contributing to the evolution of these crucial communication components. Among the studies exploring different antenna profiles, two specifically employed planar profiles [33], while others ventured into the realms of fractal, square patch, and circular patch designs, each implemented once [35]. Notably, the efficacy of planar profiles experienced a shift, with a decrease from 88% in 2020 to 83% in 2023, underscoring the dynamic nature of antenna design and the ongoing quest for optimization.

In the realm of diverse antenna profiles, the utilization of planar designs is a noteworthy trend. The studies referenced in this context provide insights into the evolving landscape of planar antennas. Despite the decrease in efficacy from 2020 to 2023, the planar profile remains a prominent choice in antenna design. This decline in efficiency prompts further exploration into the factors influencing performance and the potential trade-offs made in pursuit of other design objectives.

Beyond the dominance of planar profiles, the exploration of fractal, square patch, and circular patch designs has added another layer of complexity to the antenna design space [38], [39], [40]. These unconventional profiles, each implemented once in their respective studies, challenge traditional notions and open avenues for innovation. The efficiency ranges observed in 2020 and 2022 for fractal and patch-based designs (square and circular) fell within the range of 79% to 81%, showcasing their capability to deliver high levels of efficiency [41], [42]. This diversity in profiles suggests that there is no one-size-fits-all solution in antenna design, and the choice of profile depends on specific requirements and design objectives.

An intriguing aspect of the evolving antenna landscape is the performance metric of gain. Gain, a critical parameter in antenna performance, has demonstrated a positive trend over the years. The 2023 iteration of the planar antenna, as presented in [this work], showcased a remarkable gain of 8.2 dBi, a substantial improvement from its 2020 counterpart with a gain of 4.1 dBi. This significant increase in gain is particularly noteworthy as it occurred in the context of diminishing antenna dimensions. The ability to enhance gain while reducing the physical footprint of the antenna highlights the strides made in antenna technology, emphasizing efficiency and performance optimization.

The observed positive trend in gain across different antenna profiles suggests a concerted effort within the research community to push the boundaries of performance. Achieving higher gain is crucial for improving the overall communication capabilities of antennas, enabling them to transmit and receive signals more effectively. The 2023 planar antenna's notable gain enhancement serves as a testament to the continuous innovation in antenna design, showcasing the potential for breakthroughs even in well-established profiles.

In conclusion, the exploration of diverse antenna profiles has become a focal point in contemporary research, with planar designs, fractals, and patch-based configurations each contributing to the evolving landscape. While the efficacy of planar profiles experienced a slight decline from 2020 to 2023, the positive trend in gain, particularly exemplified by the remarkable performance of the 2023 planar antenna, highlights the dynamic nature of antenna design. The simultaneous pursuit of efficiency, gain improvement, and size reduction underscores the complexity of the trade-offs involved in optimizing antenna performance. As researchers continue to delve into innovative designs and methodologies, the future promises even more exciting developments in the field of antenna technology.

Chapter 3

Methodology

3.1 Research Methodology

The following points provide a summary of the project's research methodology: Identification of Requirements: I want to start my suggested project by outlining the microstrip patch antenna design's operational characteristics. To serve as the foundation for the design process, parameters including center frequency, bandwidth, insertion loss, isolation, return loss, and impedance matching will be calculated.

Topology Selection: In the pivotal phase of Topology Selection for the microstrip patch antenna, careful consideration is given to a range of potential configurations, including Waveguide, Strapline, and Microstrip. The goal is to identify the most fitting topology that aligns seamlessly with the specified characteristics and the overarching requirements of the project. In accordance with the project's directives, the decision is made to employ Microstrip technology for the development of the antenna. This choice is driven by the technology's reputation for compactness and versatility in integration, making it well-suited for applications where space efficiency is crucial. Additionally, the intention is to enhance the functionality of the microstrip patch antenna by incorporating filtering capabilities. This strategic decision aims to equip the antenna with the ability to selectively transmit or receive signals within a defined frequency range, aligning the design more closely with the specific requirements of the project. As the process advances, a critical choice emerges regarding the configuration of components within the selected Microstrip topology. The decision between a design with distributed components or grouped components becomes a focal point, with considerations spanning efficiency, manufacturability, and overall performance. This comprehensive evaluation ensures that the chosen topology, driven by Microstrip technology and tailored to include filtering functionalities, is well-suited to achieve the desired outcomes for the microstrip patch antenna within the parameters defined by the project.

Design Development: The microstrip patch antenna, the project seamlessly transitions into the Design Development stage. This crucial phase marks the progression from conceptualization to the concrete realization of the chosen topology. With the selected Microstrip technology and associated filtering capabilities in mind, the focus shifts towards crafting a comprehensive design blueprint. This blueprint serves as the foundational roadmap for the subsequent development process.

The Design Development stage is characterized by meticulous attention to detail, encompassing a thorough consideration of all technical specifications inherent to the project. This includes a detailed examination of parameters such as center frequency, bandwidth, insertion loss, isolation, return loss, and impedance matching. Each of these specifications plays a pivotal role in shaping the antenna's performance characteristics, ensuring that it aligns precisely with the project's predefined objectives.

The design blueprint encapsulates not only the intricate technical details but also incorporates a nuanced understanding of the chosen Microstrip topology. It strives to harmonize the theoretical aspects of the selected topology with the practical considerations necessitated by the project requirements. By integrating the technical specifications with the selected topology, the design blueprint becomes a holistic guide for the ensuing stages of simulation, prototyping, and testing.

In essence, the Design Development stage serves as the bridge between conceptualization and implementation. It is a phase where theoretical considerations materialize into a tangible plan, setting the stage for the translation of ideas into a fully functional microstrip patch antenna. The emphasis on creating a thorough design blueprint ensures that the subsequent stages of the project unfold with precision and purpose, adhering closely to the envisioned technical specifications and the intricacies of the chosen Microstrip topology.

Simulation and Design Improvement: Upon the completion of the design phase, the project seamlessly progresses into the Simulation and Prototype Testing stages, marking a crucial transition from theoretical conception to practical implementation.The designed microstrip patch antenna undergoes a rigorous simulation process using specialized software. This simulation serves as a virtual testing ground, allowing for a comprehensive evaluation of the antenna's expected performance under various conditions. The simulation results provide invaluable insights into the antenna's behavior, revealing potential strengths, weaknesses, and areas for improvement. This iterative process enables the refinement of the initial design blueprint, ensuring that it aligns optimally with the desired technical specifications. By utilizing simulation software, the project gains a deeper understanding of the antenna's anticipated operational characteristics, laying the groundwork for subsequent phases.

With the refined design in hand, the project advances to the practical realization of the microstrip patch antenna through the creation of a physical prototype. This prototype is constructed, possibly employing advanced technologies like printed circuit board (PCB) technology or other suitable approaches. The use of cutting-edge manufacturing techniques ensures precision and reliability in reproducing the designed specifications. Network analyzers and other relevant tools become instrumental in subjecting the prototype to thorough testing. This comprehensive testing process aims to validate the antenna's performance characteristics against the expectations set during the design phase. The prototype becomes a tangible manifestation of the theoretical design, offering empirical data to assess its real-world functionality.

Following the prototype testing, an iterative Design Optimization phase ensues. The observed performance characteristics of the prototype serve as critical feedback, guiding potential modifications to the design. Adjustments may be made to the network architecture or component values based on the empirical insights gained from the prototype testing. This iterative approach allows the project to fine-tune the microstrip patch antenna, aligning it more closely with the desired performance requirements. The Design Iteration phase underscores the dynamic and adaptive nature of the project, emphasizing the importance of continuous improvement to achieve optimal results.

In essence, the Simulation and Prototype Testing stages, coupled with Design Iteration, represent a dynamic cycle where theoretical precision meets practical validation. This iterative process ensures that the microstrip patch antenna evolves progressively, moving closer to the envisioned peak performance while addressing any design shortcomings identified through real-world testing.

Building and Testing the Prototype: The initial step involves the construction of a prototype, a tangible embodiment of the refined and optimized microstrip patch antenna design. Advanced manufacturing techniques, such as utilizing printed circuit board (PCB) technology or other comparable approaches, are considered for the precise replication of the theoretical blueprint. The prototype represents the bridge between theory and practice, embodying the culmination of careful design considerations.Once the prototype takes shape, a comprehensive testing regimen is initiated.

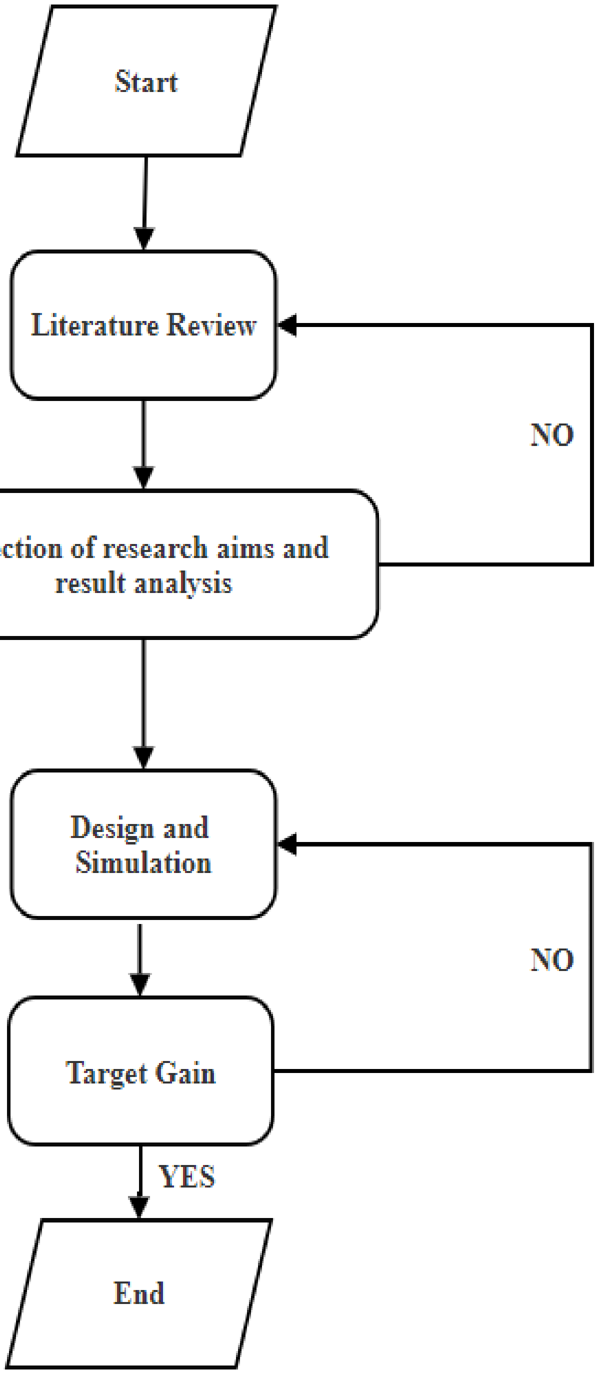

Figure 2 Research Methodology

In summary, the Building and Testing the Prototype phase represents the tangible realization of the meticulously crafted design, followed by a rigorous testing regimen. The subsequent Design Iteration phase embraces adaptability, acknowledging that the path to optimal performance involves an iterative journey of refinement and adjustment based on empirical feedback from the real-world prototype testing. This cyclical approach guarantees a robust and fine-tuned microstrip patch antenna that aligns closely with the project's performance objectives.

This meticulous strategy will guarantee a project's orderly evolution and probably lead to a reliable and effective microstrip patch antenna.

3.2 Challenge for Sustainability

As the development of an ITS-G5 antenna for vehicle communication progressed, I gained a comprehensive understanding of the manifold obstacles that accompanied this undertaking, as well as the possible remedies that could be employed to surmount them.[32]

High-frequency operation: The utilization of ITS-G5 antennas within the typical operating range of the 5.9 GHz frequency band introduces an element of complexity. It is my understanding that due to the short wavelength at this frequency, even minute design or manufacturing errors could have a significant effect on the efficacy of the antenna.

Due to the fact that the ITS-G5 operates in the same spectrum as other devices, interference is a potential hazard that may cause communication disruptions.

Environmental Implications: The energy consumption and materials utilized in the fabrication of antennas can contribute to the antenna's environmental legacy.

Scalability: An increase in the quantity of vehicles outfitted with ITS-G5 antennas may result in concomitant surges in network traffic. It is critical to effectively manage this surge in order to prevent any degradation in performance.

The durability and maintenance of vehicle-mounted antennas are compromised due to the severe conditions they are exposed to, which include physical impacts, vibrations, and a range of weather scenarios.

3.2.1 Solution for Sustainability

When contemplating the "Design of an ITS-G5 Antenna for Vehicle Communication" endeavor, it is critical to give due regard to energy sustainability. It is acknowledged that this objective can be advanced through the observance of the core tenets of sustainability, namely reduction, reuse, and recycling. [32]

Reducing entails minimizing resource consumption. In the case of the ITS-G5 antenna, this entails optimizing its design to minimize energy consumption. By utilizing sophisticated design and simulation tools, I am capable of optimizing the antenna's design to achieve maximum efficiency while conserving energy. Additionally, resource consumption can be decreased by selecting manufacturing processes that minimize waste.

Reuse: Rather than being discarded after their initial use, products that can be repurposed for the same or a different function are the focus of this principle. This may entail the antenna being engineered with modularity and upgradeability in mind. As technologies progress, for instance, specific components of the antenna could be updated or replaced in lieu of its complete replacement, thereby extending its lifecycle and minimizing waste.

Recycling is the process of transforming used materials (waste) into new products in order to prevent the pollution of potentially valuable materials. I will make every effort to ensure that the materials utilized in the construction of the ITS-G5 antenna are recyclable to the greatest extent feasible.

The antenna could be disassembled at the conclusion of its useful life so that its constituent parts could be recycled and repurposed in the fabrication of additional antennas or electronic components.

3.3 PROJECT MODEL AND PROGRESS IN SIMULATION

SOFTWARE: To automate electrical design (EDA), Keysight Technologies developed Advanced Design System (ADS)[34]. It is used by RF, microwave, and high-speed digital design engineers and researchers to develop, model, and analyze complicated electronic systems. These engineers and researchers design radio frequency (RF), microwave, and high-speed digital systems. ADS provides a full suite of tools for creating and analyzing electronic systems. Examples include schematic capture, layout design, and simulation, optimization, and EM analysis. ADS includes all of these approaches by default. It includes an easy-to-use interface, a fast simulation speed, and extensive modeling capabilities. ADS is useful since it can simulate and analyze RF and microwave circuits. One of the primary purposes of the software. The huge model library of this tool comprises active and passive components like as antennas, amplifiers, filters, and mixers. Other sections are also simulated. Using a variety of simulation engines, ADS users may appropriately model and assess complex RF and microwave circuits. Simulators make this possible. Harmonic balance, transient, and envelope simulations are examples of simulators.

Customers may develop bespoke circuit combinations using the ADS program's sophisticated layout designer. The layout editor allows you to create custom forms, place components, and route traces. Traces may be routed using these tools. A design rule checker also ensures that the arrangement fits the manufacturing process standards. This guarantees that the product is accurate. Another essential component of the ADS program is its ability to be optimized. ADS has a plethora of optimization techniques for optimizing designs for gain, noise figure, and bandwidth. Techniques in this area include gradient-based optimization, genetic algorithms, and particle swarm optimization. Using electromagnetic(EM) modeling, ADS software can accurately mimic complex structures such as antennas, transmission lines, and waveguides. The program is capable of simulating electromagnetic fields. EM simulation provides a number of capabilities. The electromagnetic behavior of these buildings is precisely modeled by ADS's EM modeling engine. This is something that FET or MoM can perform.Furthermore, the ADS software is very adaptable and extendable. VBA (Visual Basic for Applications) is pre-installed, enabling users to automate tasks and write custom scripts. An application programming interface (API) enables users to create their own plugins to enhance the capabilities of ADS. This is possible because to the package's API. To summarize, ADS is a powerful EDA tool for building and analyzing complex electrical systems. Engineers and researchers in RF, microwave, and high-speed digital design like its user-friendly interface, lightning-fast simulation speed, precise modeling, optimization methodologies, electromagnetic (EM) simulation engine, and numerous customization possibilities.

3.3.1 Procedure of Design

A rigorous scientific method will be used in the design of the 5.8 GHz Single Band Antenna for Vehicle to Everything Application. I will describe the procedure as follows:

First, I want to do a thorough analysis of current research and suggested designs for V2X antennas. Through a review of prior research and development of V2X antennas, my goal is to pinpoint best practices, present issues, and future directions for innovation.

Next, I will determine the requirement. In order to create specific design requirements at this point, I will collect information, take into account technical requirements, application demands, and environmental considerations. Key characteristics such as radiation pattern, gain, bandwidth, and operating frequency—which in this instance is 5.8 GHz—will be determined.

I will then go on and formulate the Original Idea. I want to use the Advanced Design System (ADS) software to create an initial design for the antenna based on the requirements. I will be able to precisely mimic and then recreate the model's behaviors thanks to the program.

I'll simulate the design in ADS and assess its performance in the fourth phase. Analyzing the simulation findings, including antenna efficiency, radiation pattern, gain, return loss is the fifth phase.I will next refine the first design using the insights I gained from the simulations. To improve the antenna's performance, this stage can include altering its size, shape, or material.To simulate the results of the new design, more simulations are conducted in ADS in the sixth phase. Until the performance metrics satisfy the predetermined criteria, they will be reevaluated.Subsequently, I will make incremental adjustments by comparing the Findings with the simulated results. The antenna design will go through many rounds of simulation, design, manufacturing, and testing until it precisely satisfies every requirement.Ultimately, I will finalize the design in the eighth phase. I'll complete the design after actual testing verifies that the prototype works as intended. The design may then be put into mass production and incorporated into V2X systems.I am certain that this design process will guarantee that the final antenna design is reliable, effective, and appropriate for practical use in V2X communications, thereby meeting the essential needs of such a system.

3.3.2 Antenna Design by Equation

This part of the structural and systematic design of the antenna is divided into its component parts. The arrangement of the antenna's radiating patch should be taken into account initially. This usually entails figuring out how long and how wide the patch is in this area. Building this radiating patch for an antenna requires determining a few sub-parameters. These sub-parameters are the antenna resonance frequency, the substrate height, and the substrate dielectric constant. The essential feature of how food is eaten makes up the second component. Two distinct feeding methods are used in the construction of this antenna: transformer feeding quarter wave and inset feed. Ultimately, the quarter wave transformer's feeding approach was chosen as the feeding method.

Step 1:

Calculating the Radiating Patch the Width (W) is –

$$W = \frac{c}{2f_0\sqrt{\frac{(\epsilon\gamma+1)}{2}}} \text{...} (1)$$

Step 2:

This measurement reflects the effective dielectric constant, which depends on the height, the dielectric constant, and the patch antenna's approximate distance.

$$\varepsilon_{eff} = \frac{\varepsilon\varphi+1}{2} + \frac{\varepsilon\varphi-1}{2}\left[1 + 12\frac{h}{w}\right] \text{...........................} (2)$$

Step 3:

The Effective length is –

$$L_{eff} = \frac{c}{2f_0\sqrt{\epsilon_{eff}}} \text{...} (3)$$

Step 4:

The extension length ΔL is -

$$\Delta L = 0.412h\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{n}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)} \text{..........................} (4)$$

Step 5:

The patch Length is –

$$L = L_{eff} - 2\Delta L \text{.......................................} (5)$$

Where the following parameters are used

fo = Resonance Frequency

W = radiated effective power L = The Patch Length

h = Thickness

εr = The dielectric substrate of relative permittivity

c = light of speed: 3 x 10^8 ms-1

3.3.3 SiW Antenna Design by Equation

Here Substrate Integrated Waveguide equations are given, which are used to calculate the perfect calculations of the measured simulation :

$$f_c = \frac{c}{2\pi}\sqrt{(\frac{m\pi}{a})^2 + (\frac{n\pi}{a})^2} \quad \text{.......................................(6)}$$

$$f_c = \frac{c}{2\pi} \quad \text{.......................................(7)}$$

$$a_d = \frac{a}{\sqrt{\in r}} \quad \text{.......................................(8)}$$

$$a_s = a_d - \frac{d^2}{0.95} \quad \text{.......................................(9)}$$

$$d < \frac{xg}{5} \quad \text{.......................................(10)}$$

$$p < 2d \quad \text{.......................................(11)}$$

$$\lambda_g = \frac{2\pi}{\sqrt{\frac{\in(2\pi f)^2}{\pi}}} \quad \text{.......................................(12)}$$

3.3.4 The Antenna Substrates and Dimensions

To create a high-performing V2X antenna that operates at 5.8875 GHz, it is crucial to choose the antenna substrate material wisely and accurately calculate the antenna dimensions. I will demonstrate this decision-making process by using a traditional patch antenna arrangement.

The substrate material plays a crucial role in determining the performance of the antenna. It not only acts as the foundation of the antenna but also has a substantial effect on its efficiency, bandwidth, and resonant frequency. FR-4, a dielectric composite material often used in the fabrication of printed circuit boards (PCBs), is frequently selected as the substrate for patch antennas.

The choice of FR-4 substrate with a presumed dielectric constant of 4.4 and a loss tangent of 0.02 is a crucial starting point in the design process. The dielectric constant of the substrate plays a significant role in determining the speed of signal propagation through the material, affecting the overall performance of the antenna. The loss tangent indicates the amount of energy lost as heat in the material, influencing the efficiency of the antenna. These material properties are essential considerations as they directly impact the antenna's resonance frequency and bandwidth.

The resonance frequency, set at 5.8875 GHz, is a critical parameter that dictates the frequency at which the antenna operates most efficiently. Achieving this specific resonance frequency requires careful consideration of the dimensions of the patch antenna. The author notes that the dimensions are interdependent, and any changes to one parameter necessitate corresponding modifications to the others to maintain the desired performance. This highlights the intricacies involved in antenna design and the need for precision in calculations.

An alternative method mentioned is using internet platforms to determine the antenna dimensions. However, the author underscores the need for a solid grasp of fundamental concepts and the interconnectedness of parameters to effectively build and optimize the antenna's performance. This implies that relying solely on online tools without a clear understanding of the underlying principles may lead to suboptimal results. The article provides a glimpse into the complexity of patch antenna design and optimization. It highlights the delicate balance required in selecting the substrate material, considering its dielectric properties, and meticulously determining the dimensions to achieve the desired resonance frequency. The emphasis on mutual dependency among parameters reinforces the need for a systematic and well-informed approach to antenna design.

In conclusion, the article serves as a concise overview of the considerations and processes involved in designing a patch antenna using FR-4 substrate. The author's commitment to precision, consultation with experts, and the understanding of fundamental concepts contribute to a comprehensive approach in ensuring the antenna's optimal performance at the specified resonance frequency.

3.4 Design of the Antenna

Design parameters are given below:

TABLE I DESIGN PARAMETERS

Parameter	**Details**
W	Patch Width
L	Patch Length
Tw	Transmission Line Width
Tl	Transmission Line Length
InW	Inset Width
InL	Inset Length

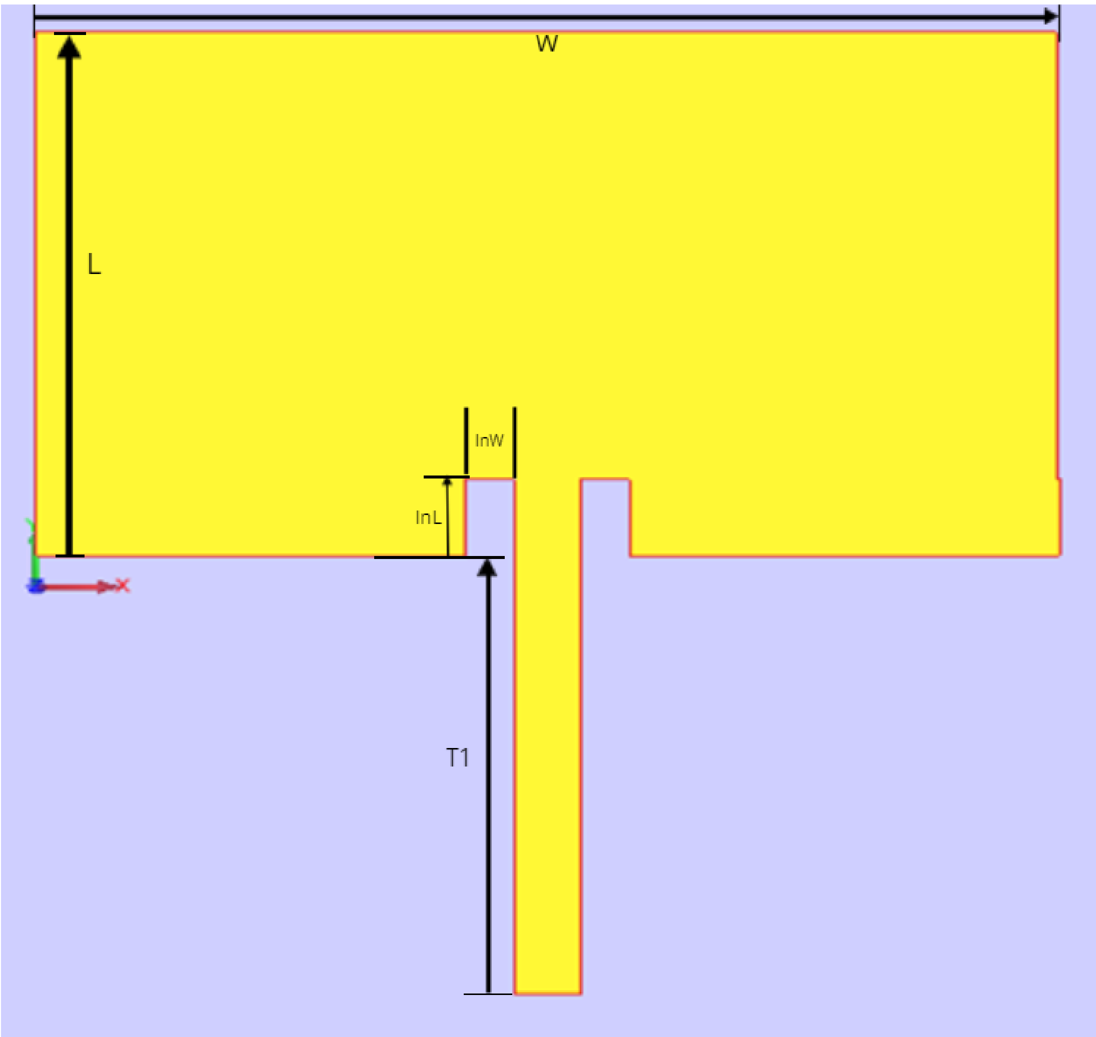

Figure 3 Depicts the arrangement of the antenna

The subsequent content provides a foundational understanding for conducting simulations in our work.S11, commonly denoted as the return loss, serves as a metric to assess the level of impedance matching between an antenna or network and its source impedance, typically set at 50 ohms.

A lower S11 value signifies excellent impedance matching, minimizing power reflection and ensuring efficient power transmission, which is pivotal for optimal operational efficiency. Incorporating the S11 parameter in this project is crucial to ensure the antenna is suitably designed for its intended operational conditions.

Current distribution refers to how electrical current is spread across the antenna's surface, influencing its radiation pattern, impedance, and polarization. Understanding the current distribution on the antenna's surface is a vital aspect of this project, essential for optimizing the antenna's design to meet required parameters.

Antenna Parameters

Frequency (GHz)		5.88889
Input power (Watts)		0.00240141
Radiated power (Watts)		0.00201328
Directivity(dBi)		8.97531
Gain (dBi)		8.20968
Radiation efficiency (%)		83.8373
Maximum intensity (Watts/Steradian)		0.00126539
Effective angle (Steradians)		1.59103
Angle of U Max (theta, phi)	47	270
E(theta) max (mag,phase)	0.97643	-44.8834
E(phi) max (mag,phase)	0.00281033	-152.663
E(x) max (mag,phase)	0.00281033	-152.663
E(y) max (mag,phase)	0.665924	135.117
E(z) max (mag,phase)	0.714116	135.117

Figure 4 Antenna Parameters

Gain, representing an antenna's ability to focus input power in a specific direction, is a critical factor. A high-gain antenna exhibits robust signal transmission or reception in specific directions while potentially showing weaker performance in other directions. A thorough comprehension of the antenna's gain is indispensable for ensuring effective communication in the intended direction.

Directivity characterizes an antenna's ability to concentrate energy in a specific direction during transmission. High directivity allows an antenna to focus more power in a particular direction, minimizing power distribution in other directions. Understanding the antenna's directivity in this project is crucial, directly impacting the efficiency of V2X communications.

Efficiency gauges the amount of input power that an antenna radiates, considering factors like conductor and dielectric losses. A highly efficient antenna can emit a greater proportion of input power, enhancing the intensity and reach of the broadcast signal. Evaluating the antenna's efficiency in this project is imperative to ensure optimal performance and reliability of the V2X communication system.

Chapter 4

Simulation and Result Analysis

4.1.1 Overview

The following material provides a fundamental comprehension for executing the simulation in my project [36].S11, commonly referred to as the return loss, quantifies the degree of impedance matching between an antenna or network and its source impedance, typically 50 ohms.

A low S11 value indicates excellent impedance matching and minimum power reflection, which is crucial for effective power transmission and maximum operational efficiency. It is essential to take into account the S11 parameter in this project to guarantee that the antenna is appropriately constructed for its intended operating circumstances.

Current distribution pertains to the manner in which electrical current is distributed over the surface of the antenna. The antenna's radiation pattern, impedance, and polarization are influenced by it.

An essential aspect of this project is comprehending the present distribution of electrical current on the surface of the antenna. This understanding is crucial for optimizing the design of the antenna to fulfill the necessary parameters.Gain: The gain of an antenna quantifies its capacity to focus input power towards emission in a particular direction. An antenna with high gain exhibits strong signal transmission or reception in certain directions while showing weaker performance in other directions. To guarantee good communication in the intended direction, it is crucial to have a thorough grasp of the antenna's gain for this project.Directivity refers to an antenna's capacity to concentrate energy in a particular direction during transmission. An antenna with high directivity is capable of concentrating a greater amount of power in a certain direction while minimizing power distribution in other directions. Understanding the antenna's directivity in this project is crucial since it directly impacts the efficiency of V2X communications.

Efficiency is the measure of the amount of input power that an antenna radiates, with the remaining power being wasted as heat owing to variables like conductor and dielectric losses.

A highly effective antenna has the ability to emit a greater proportion of the input power, hence enhancing the intensity and reach of the broadcast signal.

It is important to evaluate the antenna's effectiveness in this project to guarantee optimal performance and dependability of the V2X communication system.

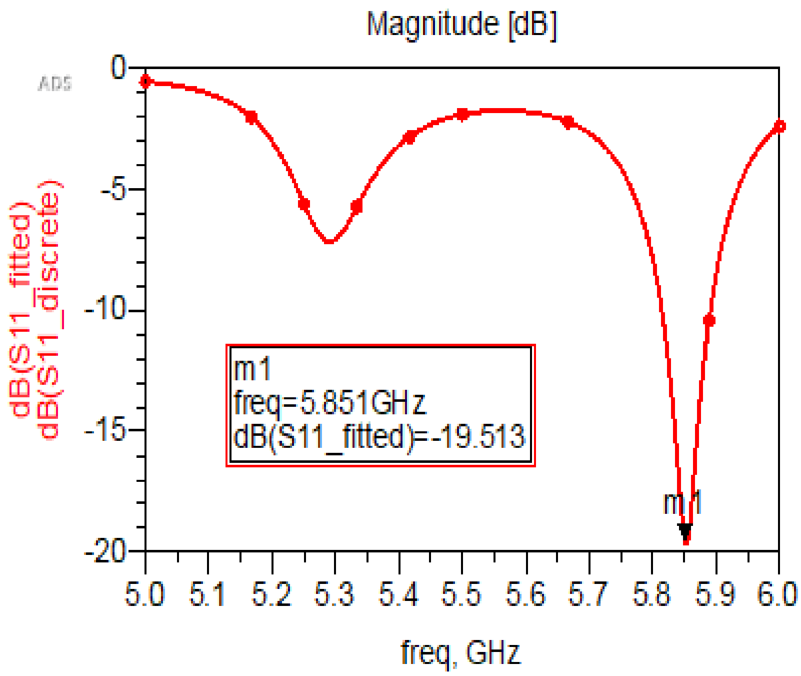

Figure 5 Initial result (S11) of the proposed design of single band antenna

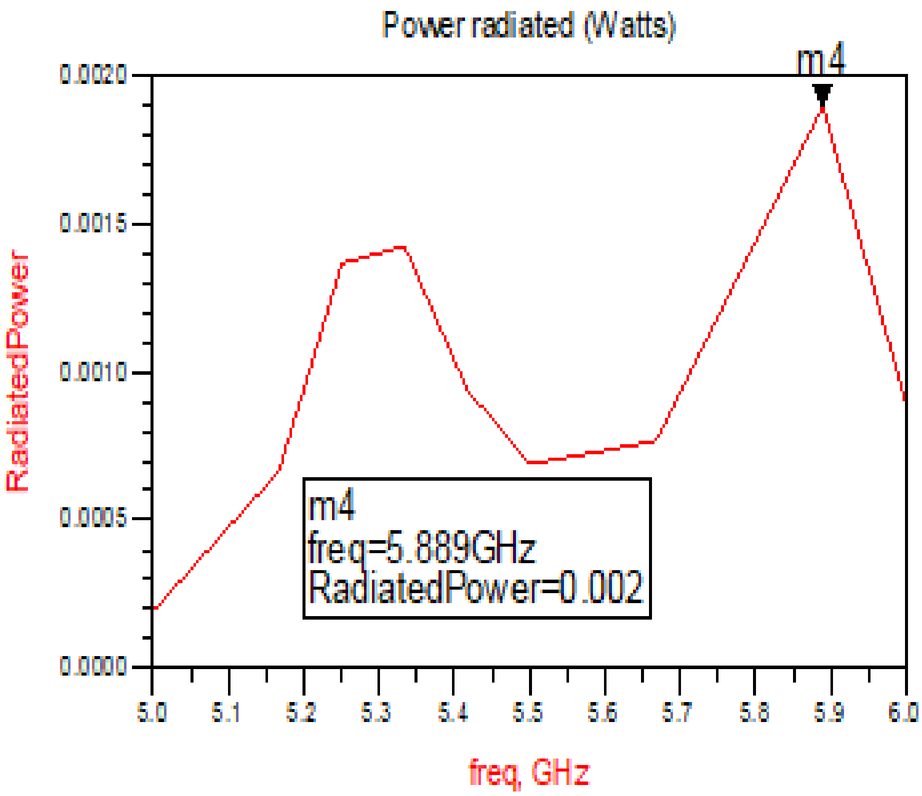

Figure 6 Radiated power

The given S11 value is -19.513 dB at 5.851GHz. Typically, for antennas, a lower absolute value of S11 indicates better matching, as S11 represents how much power is reflected back from the antenna instead of being radiated. Commonly, an S11 value less than -10 dB is considered acceptable, indicating that less than 10% of the power is reflected back. With an S11 value of -19.513dB, the antenna exhibits excellent impedance matching, meaning a very small portion of the signal is reflected back, and most of the power is accepted by the antenna.

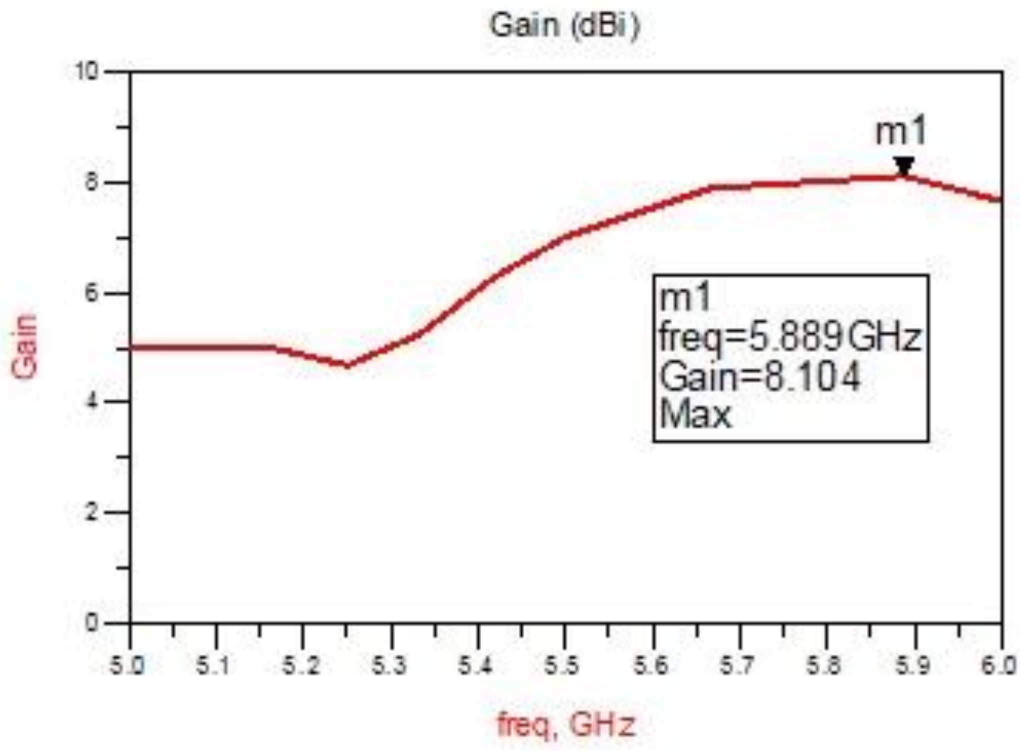

Figure 7 Gain

The assessed gain of the antenna registers at 8.104 dBi, a noteworthy metric that reflects a commendable antenna design, particularly when this value aligns with the stipulated design requirements. This gain value signifies the antenna's capability to focus the signal, with an 8.104 dBi gain outperforming an isotropic reference antenna. The isotropic reference antenna serves as a theoretical benchmark for comparison, and the achieved gain exceeding this reference suggests superior directional transmission or reception characteristics.

Furthermore, the directivity of the antenna is reported at 8.881 dB. The fact that the directivity slightly surpasses the gain (8.104 dBi) suggests that some energy is lost in the antenna system. This discrepancy prompts attention to the efficiency parameter, as the difference between directivity and gain indicates potential losses in the antenna's ability to concentrate energy in a specific direction during transmission. The efficiency parameter becomes a critical factor to explore, aiming to assess and mitigate any energy losses within the antenna system.

In summary, the gain value of 8.104 dBi highlights the antenna's prowess in focusing the signal, surpassing the performance of an isotropic reference antenna. The observed directivity of 8.881 dB, while indicative of effective energy concentration, also prompts a closer examination of the efficiency parameter to address potential energy losses and ensure optimal performance in the overall V2X communication system.

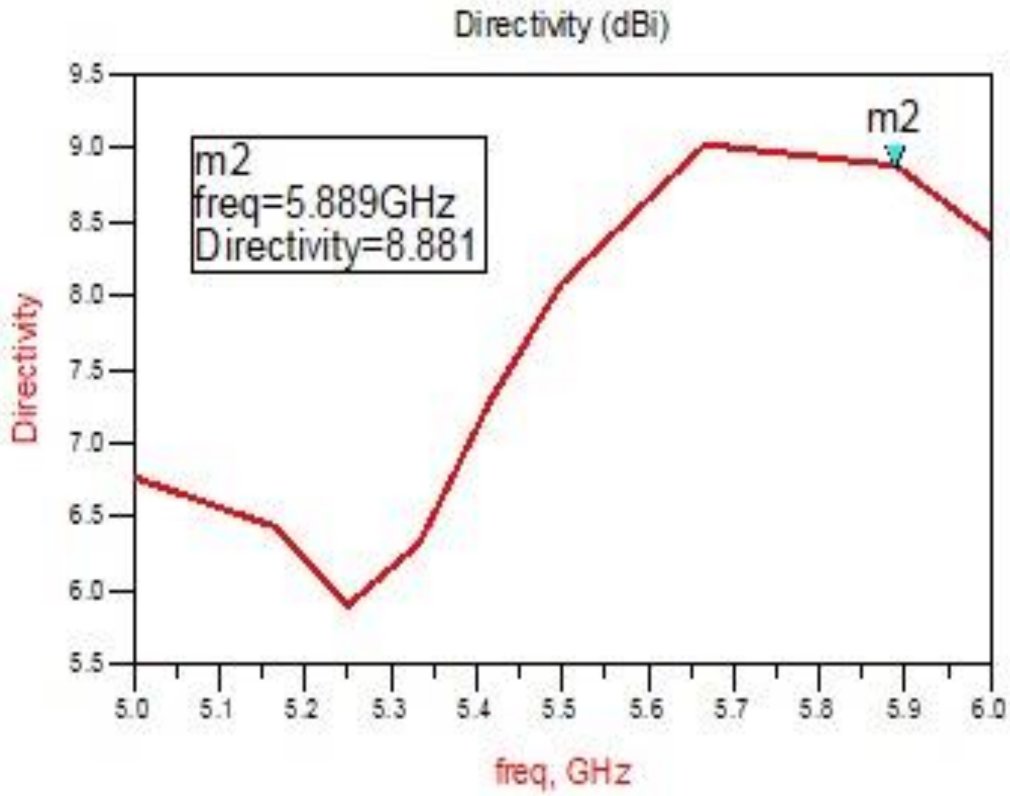

Figure 8 Directivity

The operational efficiency of the antenna stands at an impressive 84%. This metric serves as a crucial measure of the antenna's proficiency in converting input power into radiated power.

The efficiency value, quantifying the percentage of received power that is effectively radiated, indicates that 84% of the input power contributes to the transmission, while the remaining 16% is either dissipated as heat or absorbed by the antenna itself. This high-efficiency rate is a compelling indicator of a meticulously designed and well-constructed antenna.

Such a notable efficiency level underscores the antenna's ability to optimize the utilization of input power, ensuring that a substantial proportion is effectively transformed into radiated energy. This efficiency not only enhances the overall effectiveness of the V2X communication system but also signifies a judicious utilization of resources.

A high-efficiency antenna plays a pivotal role in maximizing the reach and intensity of the broadcast signal while minimizing energy losses, contributing to the reliability and performance stability of the communication infrastructure.

In essence, the reported efficiency of 84% establishes the antenna as a robust component within the V2X communication system, showcasing a design and construction that prioritizes effective power conversion and minimizes energy wastage. This efficiency attribute is instrumental in reinforcing the antenna's role as a key enabler for seamless and reliable communication in vehicular networks.

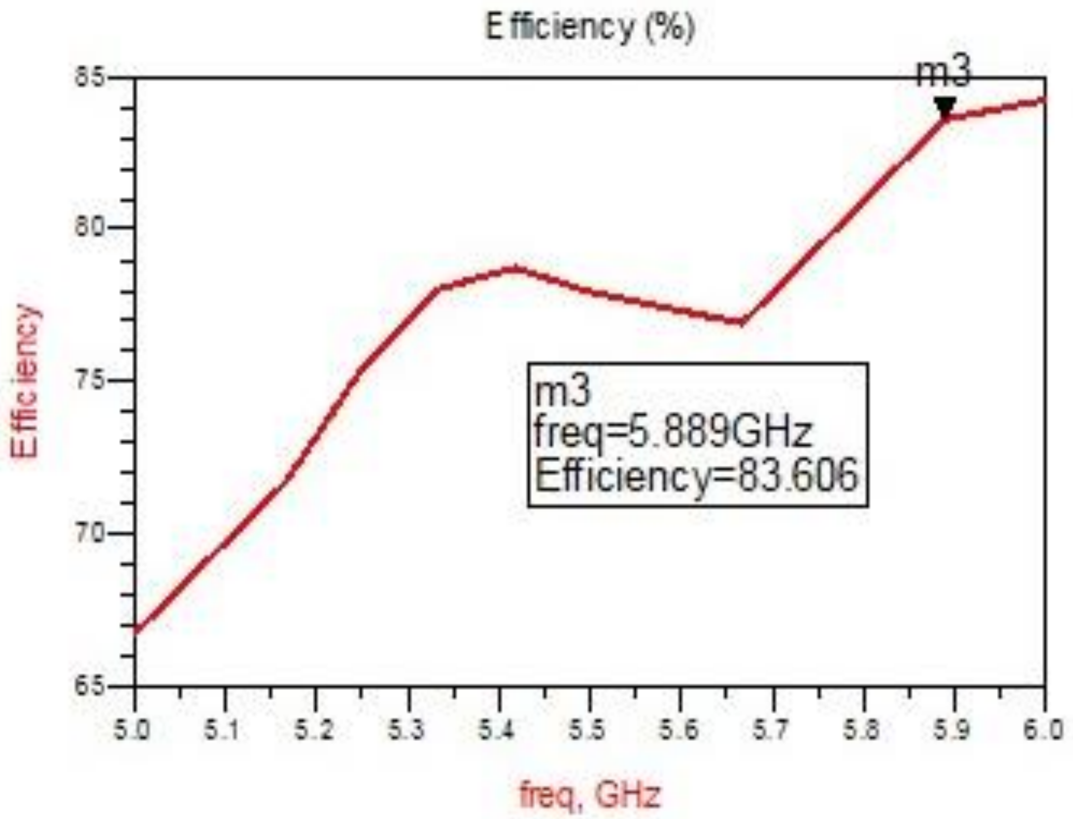

Figure 9 Efficiency

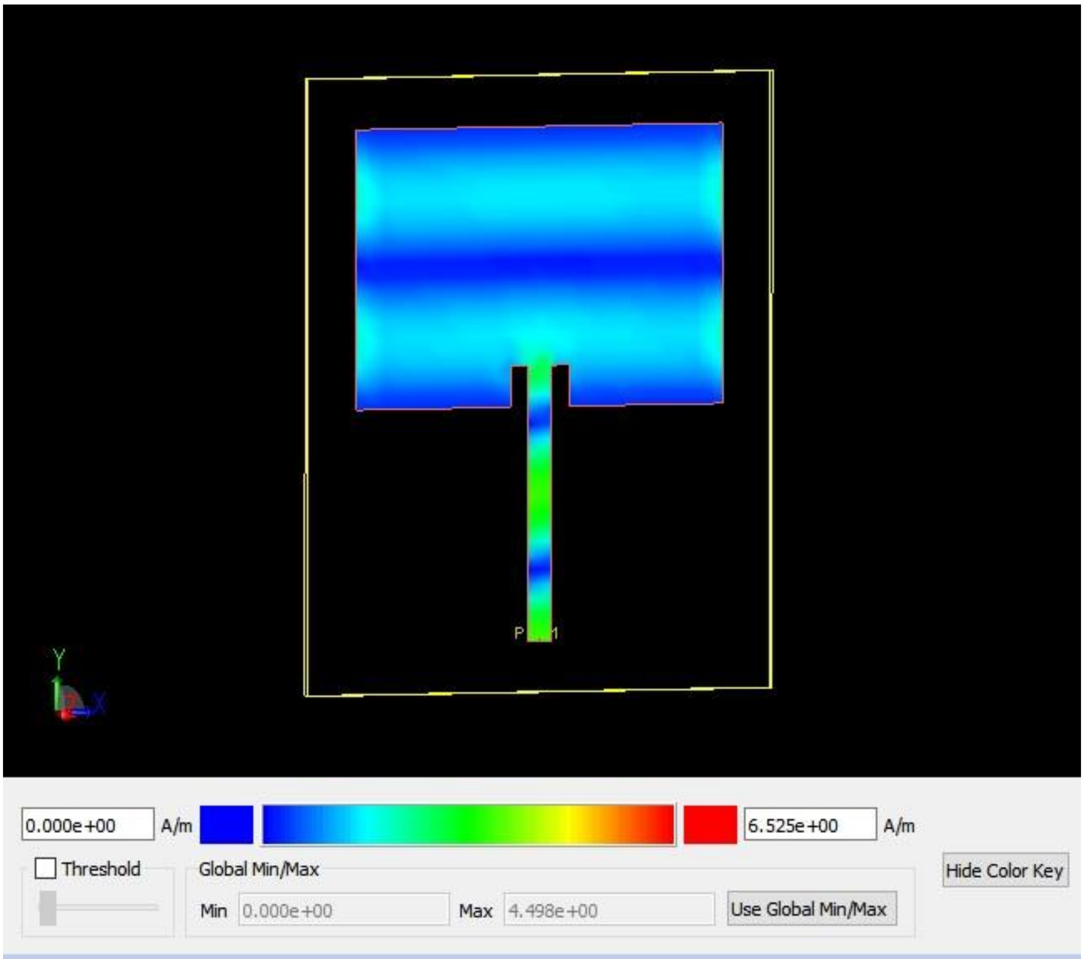

Figure 10 Current Distribution

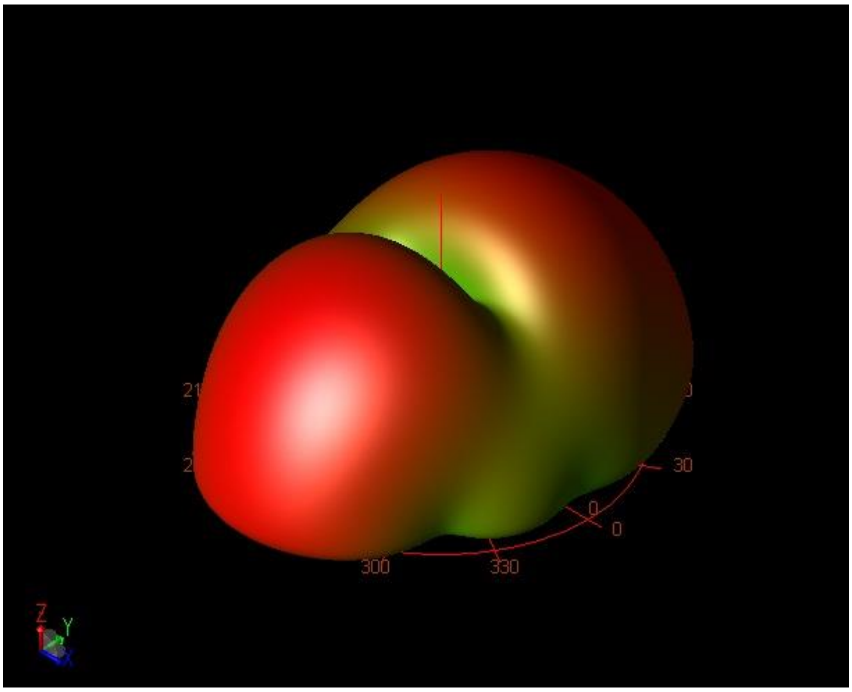

Figure 11 3D model of the proposed design

To encapsulate the advancements observed from 2020 to 2023, the field of antenna design underwent a transformative phase marked by notable refinements. This period witnessed a discernible upswing in both gain and efficiency, key parameters that define the effectiveness of antennas in wireless communication systems. It's noteworthy that these improvements were achieved, albeit with the trade-off of reducing overall dimensions, a testament to the dynamic nature of design considerations during this timeframe.

The enhancements in gain and efficiency achieved through these refinements hold significant implications for the advancement of wireless communication technologies. The ability to attain higher gains while maintaining or improving efficiency is a promising trend, as it contributes to the ongoing evolution and optimization of communication systems. These achievements highlight the continuous commitment of researchers and innovators to address the evolving demands and complexities within the realm of wireless communications. Overall, the progress made in antenna design during this period lays a robust foundation for the future development of more efficient and effective wireless communication systems.

TABLE II COMPARISON TABLE WITH RELATED WORKS

Refs.	**Year**	**Operating band (GHz)**	**Total size (mm^3)**	**Gain (dBi)**	**Efficiency (%)**	**S11**	**Application**
[27]	2021	5.8-5.9	60×60 ×0.79	5.8	90	-28	V2X
[28]	2022	5.85-5.95	21 ∗ 21 ∗ 1.6	6	79	-16.2	V2X-C
[29]	2022	3.3-4	68.71×48.58	4.89	81	-20.8	V2X
[30]	2022	5.8-5.9	85 × 85 × 0.1	3.2	90	-22.3	V2X
This work	2023	5.8	46.64×36.02 ×1.5	8.1	85	-19.087	V2V

Chapter 5
Conclusion

5.1 Discussion

In the rapidly evolving realm of intelligent transportation systems, this thesis embarked on a comprehensive journey to design, simulate, and optimize a microstrip patch antenna tailored explicitly for Vehicle-to-Vehicle (V2V) communication at 5.851 GHz. As the automotive industry undergoes a paradigm shift driven by technological evolution, our research has endeavored to meet the multifaceted challenges of ensuring robust and efficient communication within the vehicular network. The culmination of our endeavors has yielded an antenna that not only satisfies the stringent requirements of V2V communication but also sets a new standard with exemplary performance metrics— a low S11 value of -19.513 dB, a high gain of 8.104, an impressive directivity of 8.881, and a remarkable efficiency rating of 84%.

The design process was a meticulous exploration of the intricate parameters that define microstrip patch antennas. From geometric intricacies to substrate material characteristics and fabrication techniques, each facet played a crucial role in shaping the antenna's performance. Leveraging advanced electromagnetic simulation tools, we engaged in a meticulous refinement of the antenna's geometry. This process aimed at achieving an optimal impedance match, minimizing signal reflection, and enhancing signal integrity within the V2V network—a critical aspect for ensuring reliable communication in the ever-changing and demanding vehicular environment.

The high gain achieved by the antenna not only ensures reliable and long-range communication between vehicles but also contributes significantly to the safety and efficiency of intelligent transportation systems. The impressive directivity is equally vital, allowing for the concentration of radiation in specific directions. This optimization enhances signal strength and coverage within the V2V communication domain, overcoming the challenges posed by the dynamic and complex nature of vehicular communication scenarios.

Efficiency, often an overlooked aspect of antenna design, takes center stage with our antenna boasting an impressive 84% rating. Beyond being a mere performance metric, this efficiency rating underscores a commitment to sustainable and energy-conscious communication—a critical consideration in an era where environmental consciousness permeates every facet of design. The efficient conversion of input power into radiated energy not only enhances the overall viability and longevity of the communication system but also aligns seamlessly with the contemporary emphasis on environmentally conscious design in the automotive industry.

This research transcends the immediate practical applications of antenna design and contributes significantly to the theoretical understanding of microstrip patch antennas. By exploring practical considerations, including the impact of substrate material selection, we provide a nuanced understanding that ensures the feasibility of implementing the proposed antenna in real-world automotive environments.

To ascertain the practicality and versatility of the designed antenna, a series of comprehensive performance evaluations were conducted under diverse conditions. Varying vehicle orientations and environmental factors were taken into account, revealing the antenna's robustness and stability. These findings not only validate its suitability for challenging V2V communication scenarios but also underscore its potential for seamless integration into the complex dynamics of modern intelligent transportation systems.

In summary, the meticulously designed microstrip patch antenna represents not merely a technological feat but a paradigm shift in vehicular communication. Its confluence of exceptional performance metrics and sustainability considerations positions it at the forefront of technological advancements in the automotive industry. As the automotive landscape continues to undergo transformative changes, our antenna stands as a beacon guiding the evolution of intelligent transportation systems. Its impact is poised to be enduring, contributing significantly to the creation of safer, more efficient, and interconnected transportation networks. This research underscores the transformative potential of cutting-edge technology in shaping the future of mobility—a future where innovation and connectivity converge to redefine the way we traverse and experience the world.

References

1. ‘The 2010-2019 top five survey papers of IEEE transactions on Intelligent Transportation Systems’ (2021a) IEEE Intelligent Transportation Systems Magazine, 13(2), pp. 256–256. doi:10.1109/mits.2021.3068808
2. Dimitrakopoulos, G. and Demestichas, P. (2010) ‘Intelligent Transportation Systems’, IEEE Vehicular Technology Magazine, 5(1), pp. 77–84. doi:10.1109/mvt.2009.935537.
3. Figueiredo, L. et al. (no date) ‘Towards the development of Intelligent Transportation Systems’, ITSC 2001. 2001 IEEE Intelligent Transportation Systems. Proceedings (Cat. No.01TH8585) [Preprint]. doi:10.1109/itsc.2001.948835.
4. Ranson, jack . “The Evolution of ITS in the UK: A History.” WJ Group, 28 Feb. 2023, www.wj.uk/advice/history-intelligent-transportation-systems. Accessed 17 Dec. 2023.
5. Deny, Hassae. “TfW Introduces Augmented Reality Maps for Stations.” Intelligent Transport, www.intelligenttransport.com/transport- news/146783/tfw-introduces-augmented-reality-maps-for-stations. Accessed 17 Dec. 2023.
6. Quin, Rakw. “TfWM Introduces Drone Team to Reduce Traffic Congestion.” Intelligent Transport, www.intelligenttransport.com/transport-news/146385/tfwm-introduces-drone-team-to-reduce-traffic-congestion/. Accessed 17 Dec. 2023.
7. Kelvin, Hanre. “Intelligent Transportation Systems Market to Reach $57.44 Billion in 2024.” Intelligent Transport, www.intelligenttransport.com/transport-news/64582/intelligent-transportation- system-market. Accessed 17 Dec. 2023. Zine, Qmilqz. Https://Www.canva.com/Pro. 8 July 2016.
9. Altinel, B., Wollenschlager, F. and Hein, M.A. (2019) ‘Interference tests of its- G5 vehicle-to-vehicle communication networks with virtual drive tests’, 2019 IEEE International Conference on Connected Vehicles and Expo (ICCVE) [Preprint]. doi:10.1109/iccve45908.2019.8965140.
10. Mavromatis, I., Tassi, A. and Piechocki, R.J. (2019) ‘Operating its-G5 DSRC over unlicensed bands: A city-scale performance evaluation’, 2019 IEEE 30th Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC) [Preprint]. doi:10.1109/pimrc.2019.8904214.

11. Unterhuber, P., Lehner, A. and de Ponte Müller, F. (2016) 'Measurement and analysis of its-G5 in Railway Environments', Lecture Notes in Computer Science, pp. 62–73. doi:10.1007/978-3-319-38921-9_7.
12. Karoui, M., Freitas, A. and Chalhoub, G. (2020) 'Performance comparison between LTE-V2X and its-G5 under realistic urban scenarios', 2020 IEEE 91st Vehicular Technology Conference (VTC2020-Spring) [Preprint]. doi:10.1109/vtc2020-spring48590.2020.9129423.
13. Gizzini, A.K. et al. (2020) 'Enhancing least square channel estimation using Deep Learning', 2020 IEEE 91st Vehicular Technology Conference (VTC2020- Spring) [Preprint]. doi:10.1109/vtc2020-spring48590.2020.9128890.
14. Coll-Perales, B., Gozalvez, J. and Gruteser, M. (2019) 'Sub-6GHz assisted Mac for Millimeter Wave Vehicular Communications', IEEE Communications Magazine, 57(3), pp. 125–131. doi:10.1109/mcom.2019.1800509.
15. Sattiraju, R. et al. (2020) 'Link level performance comparison of C-V2X and its-G5 for Vehicular Channel Models', 2020 IEEE 91st Vehicular Technology Conference (VTC2020-Spring) [Preprint]. doi:10.1109/vtc2020- spring48590.2020.9129366.
16. Mannoni, V. et al. (2019) 'A comparison of the V2X communication systems: Its-G5 and C-V2X', 2019 IEEE 89th Vehicular Technology Conference (VTC2019-Spring) [Preprint]. doi:10.1109/vtcspring.2019.8746562.
17. Rahman, N.A. et al. (2020) 'Compact bidirectional circularly polarized dedicated short range communication antenna for on-board unit vehicle-to- everything applications', International Journal of RF and Microwave Computer-Aided Engineering, 30(5). doi:10.1002/mmce.22174.
18. Ghiaasi, G. et al. (2022) 'SDR-based communication sniffing for determining the proliferation of its-G5', 2022 16th European Conference on Antennas and Propagation (EuCAP) [Preprint]. doi:10.23919/eucap53622.2022.9769381.
19. Parra, I. et al. (2019) 'Performance analysis of vehicle-to-vehicle communications for critical tasks in autonomous driving', 2019 IEEE Intelligent Transportation Systems Conference (ITSC) [Preprint]. doi:10.1109/itsc.2019.8917302.
20. Gholamhosseinian, A. and Seitz, J. (2022) 'Empirical estimation of ETSI its- G5 performance over an IPv6-based platform', 2022 IEEE International Performance, Computing, and Communications Conference (IPCCC) [Preprint]. doi:10.1109/ipccc55026.2022.9894344.

21. Mavromatis, I. et al. (2018) ‘A city-scale its-G5 network for next-generation intelligent transportation systems: Design Insights and challenges’, Ad-hoc, Mobile, and Wireless Networks, pp. 53–63. doi:10.1007/978-3-030-00247-3_5.
22. McCarthy, B. and O’Driscoll, A. (2019) ‘OpenCV2X Mode 4: A simulation extension for cellular vehicular communication networks’, 2019 IEEE 24th International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD) [Preprint]. doi:10.1109/camad.2019.8858436.
23. Almeida, J., Ferreira, J. and Oliveira, A. (2016) ‘Development of an its-G5 station, from the physical to the mac layer’, Intelligent Transportation Systems, pp. 1–36. doi:10.1201/9781315370866-2.
24. Maliatsos, K. et al. (2020) ‘Hybrid multi-antenna techniques for V2X Communications—prototyping and experimentation’, Telecom, 1(2), pp. 80–95. doi:10.3390/telecom1020007.
25. Honggang, H. et al. (2016) ‘Design of hexagon microstrip antenna for vehicle- to-vehicle communication’, The Journal of China Universities of Posts and Telecommunications, 23(4), pp. 69–76. doi:10.1016/s1005-8885(16)60047-x.
26. Kornek, D. et al. (2010) ‘Effects of antenna characteristics and placements on a vehicle-to-vehicle channel scenario’, 2010 IEEE International Conference on Communications Workshops [Preprint]. doi:10.1109/iccw.2010.5503935.
27. Banerjee, S. et al. (2021) ‘Half mode semi-hexagonal SIW antennas and arrays for cellular V2X communication’, Microsystem Technologies, 27(10), pp. 3639–3651. doi:10.1007/s00542-020-05127-7.
28. Vallikannu, R. et al. (2022) ‘A miniaturized defected ground patch antenna for its 5G-V2X-C applications’, 2022 International Conference on Computer Communication and Informatics (ICCCI) [Preprint]. doi:10.1109/iccci54379.2022.9741033.
29. Fitrianingrum, V.A. and Suryana, J. (2022) ‘Antenna Design for V2X application in 5G network’, 2022 16th International Conference on Telecommunication Systems, Services, and Applications (TSSA) [Preprint]. doi:10.1109/tssa56819.2022.10063920.
30. Sujanth Narayan, K.G. and Baskaradas, J.A. (2023) ‘A conformal dual-band CPW-MIMO antenna for 5G-V2X communication’, IETE Journal of Research, pp. 1–19. doi:10.1080/03772063.2023.2256352.

31. Han, Fred. Https://Www.everythingrf.com/Rf-Calculators/Dipole-Antenna-Length-Calculator. 8 Jan. 2021.
32. Sun, D. and Wei, C. (2016) ‘Analysis and design of 4 × 4 MIMO-Antenna Systems in mobile phone’, Journal of Computer and Communications, 04(02), pp. 26–33. doi:10.4236/jcc.2016.42004.
33. Hasan , Insia. “Reduce, Reuse and Recycle: Simple Routines to Take a Stand for the Environment.”Www.santander.com, www. santander. com/en/stories/reduce-reuse and-recycle-the-three-rs-to-help- the-planet.
34. Li, Z. et al. (2020) ‘A dual-band omnidirectional circular polarized antenna using composite right/left-handed transmission line with rectangular slits for unmanned aerial vehicle applications’, IEEE Access, 8, pp. 100586–100595. doi:10.1109/access.2020.2999369.
35. Kaur, M. and Sivia, J.S. (2019) ‘Giuseppe Peano and Cantor set fractals based miniaturized hybrid fractal antenna for biomedical applications using artificial neural network and Firefly algorithm’, International Journal of RF and Microwave Computer-Aided Engineering, 30(1). doi:10.1002/mmce.22000.
36. Khan, I. et al. (2022) ‘A wideband high-isolation microstrip MIMO circularly-polarized antenna based on parasitic elements’, Materials, 16(1), p. 103. doi:10.3390/ma16010103.
37. Sadi, Goruc.Https://Commons.wikimedia.org/Wiki/File:Flag_of_Switzerland.svg. 5 May 2022.
38. Khan, A.A. and Mandal, M.K. (2019) ‘Compact self-diplexing antenna using dual-mode SIW square cavity’, IEEE Antennas and Wireless Propagation Letters, 18(2), pp. 343–347. doi:10.1109/lawp.2018.2890790.
39. Subba Ramaiah, V. et al. (2021) ‘Teaching and learning based 5G cognitive radio application for future application’, 2021 International Conference on Computational Intelligence and Knowledge Economy (ICCIKE) [Preprint]. doi:10.1109/iccike51210.2021.9410797.
40. Chaturvedi, D. and Raghavan, S. (2017) ‘Circular quarter-mode SIW antenna for WBAN application’, IETE Journal of Research, 64(4), pp. 482–488. doi:10.1080/03772063.2017.1358115.
41. Sharma, B.L., Mathur, D. and Sharma, M.K. (2023) ‘Siw-cavity based frequency reconfigurable antenna for IOT, WLAN, and 5G applications’, Frequenz, 77(7–8), pp. 413–424. doi:10.1515/freq-2022-0173.

42. Kumar, B.L. et al. (2021) ‘Design and analysis of circular patch antenna’, Journal of Physics: Conference Series, 1804(1), p. 012200. doi:10.1088/1742- 6596

T191067_Rihan

by Maharaz 1m

Submission date: 12-Feb-2024 03:37AM (UTC-0600)

Submission ID: 2249890584

File name: T191067_Rihan.pdf (751.53Kb)

Word count: 12508

Character count: 75305

T191067_Rihan

ORIGINALITY REPORT

13%	6%	6%	9%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to University of Hertfordshire Student Paper	4%
2	dspace.iiuc.ac.bd:8080 Internet Source	1%
3	Kawtar Jellid, Tomader Mazri. "An Enhanced Algorithm of Improved Response Time of ITS-G5 Protocol", International Journal of Advanced Computer Science and Applications, 2023 Publication	<1%
4	Submitted to University of Nottingham Student Paper	<1%
5	Almeida, Joao Miguel Pereira de. "Dependable Wireless Communications for Vehicular Networks", Universidade de Aveiro (Portugal), 2020 Publication	<1%
6	Alzahrani, Ahmed. "Realistic Adaptive Signal Control Under Platooned Connected Vehicles	<1%

Environment", The Florida State University, 2023
Publication

---

7 Microstrip Patch Antennas A Designer’s Guide, 2003.
Publication
<1%

---

8 www.imanagerpublications.com
Internet Source
<1%

---

9 eprints.qut.edu.au
Internet Source
<1%

---

10 researchr.org
Internet Source
<1%

---

11 Submitted to British University In Dubai
Student Paper
<1%

---

12 Submitted to South Bank University
Student Paper
<1%

---

13 Submitted to The University of the West of Scotland
Student Paper
<1%

---

14 Submitted to University of Northumbria at Newcastle
Student Paper
<1%

---

15 odr.chalmers.se
Internet Source
<1%

16	Donglin Wang, Oneza Saraci, Raja R. Sattiraju, Qiuheng Zhou, Hans D. Schotten. "Effect of Variable Physical Numerologies on Link-Level Performance of 5G NR V2X", 2022 IEEE 8th International Conference on Computer and Communications (ICCC), 2022 Publication	<1 %
17	Submitted to Middlesex University Student Paper	<1 %
18	Signals and Communication Technology, 2012. Publication	<1 %
19	www.iss.ac.cn Internet Source	<1 %
20	Anjajo, Kalkidan Woldemariam. "Static I-V Curve and Aging Test for PIM Characterization in Metallic Contacts", Missouri University of Science and Technology, 2023 Publication	<1 %
21	Submitted to University of Bedfordshire Student Paper	<1 %
22	www.grafiati.com Internet Source	<1 %
23	Eduard Zadobrischi, Mihai Dimian, Mihai Negru. "The Utility of DSRC and V2X in Road	<1 %

Safety Applications and Intelligent Parking: Similarities, Differences, and the Future of Vehicular Communication", Sensors, 2021
Publication

24	Narimane Awada Mislmani, Divitha Seetharamdoo. "Metasurface antenna system for pedestrian to vehicle communications based on IEEE 802.11p: design and evaluation", 2022 16th European Conference on Antennas and Propagation (EuCAP), 2022 Publication	<1 %
25	scirp.org Internet Source	<1 %
26	wiredspace.wits.ac.za Internet Source	<1 %
27	www.scribd.com Internet Source	<1 %
28	1library.net Internet Source	<1 %
29	www.diva-portal.org Internet Source	<1 %
30	www.researchgate.net Internet Source	<1 %
31	"Abstract cards", 2014 44th European Microwave Conference, 2014. Publication	<1 %

32	"Communication Technologies for Vehicles", Springer Science and Business Media LLC, 2017 Publication	<1 %
33	5g-drive.eu Internet Source	<1 %
34	Golsa Ghiaasi, Thomas Blazek, Fjolla Ademaj, Julian Karoliny et al. "SDR-Based Communication Sniffing for Determining the Proliferation of ITS-G5", 2022 16th European Conference on Antennas and Propagation (EuCAP), 2022 Publication	<1 %
35	Xu, Han. "Queuing Modelling and Performance Analysis of Content Transfer in Information Centric Networks", University of Exeter (United Kingdom), 2023 Publication	<1 %
36	export.arxiv.org Internet Source	<1 %
37	lup.lub.lu.se Internet Source	<1 %
38	sciforum.net Internet Source	<1 %
39	utpedia.utp.edu.my Internet Source	<1 %

40	www.semanticscholar.org Internet Source	<1 %
41	"Innovations in Smart Cities Applications Volume 4", Springer Science and Business Media LLC, 2021 Publication	<1 %
42	"Intelligent Network Management and Control", Wiley, 2021 Publication	<1 %
43	Mohamed Hanaoui, Mounir Rifi. "Elliptical Slot Rectangular Patch Antenna Array with Dual Band Behaviour for Future 5G Wireless Communication Networks", 2019 7th Mediterranean Congress of Telecommunications (CMT), 2019 Publication	<1 %
44	Kawtar Jellid,Tomader Mazri. "ITS-G5 vs C-V2X for Autonomous Car", Journal of Networking and Communication Systems (JNACS), 2023 Publication	<1 %
45	Khaleel Ahmad, Halimjon Khujamatov, Amir Lazarev, Nargiza Usmanova, Mona Alduailij, Mai Alduailij. "Internet of Things-Aided Intelligent Transport Systems in Smart Cities: Challenges, Opportunities, and Future", Wireless Communications and Mobile Computing, 2023 Publication	<1 %

46	Qi Wu, Yahui Zhou, Shuang Guo. "An L-Sleeve L-Monopole Antenna Fitting a Shark-fin Module for Vehicular LTE, WLAN and car-to-car Communications", IEEE Transactions on Vehicular Technology, 2018 Publication	<1 %
47	biblio.ugent.be Internet Source	<1 %
48	peerj.com Internet Source	<1 %

Exclude quotes	On	Exclude matches	Off
Exclude bibliography	On		