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Review and Design of a Simple 60 GHz Microstrip Antenna for Enhanced 5G Performance

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The emergence of 5G technology has drawn the attention of researchers to the 60 GHz frequency spectrum which provides a wide bandwidth and massive data transfer with high data rates and low latency communication. Wireless systems utilizing 60 GHz enable multiantenna systems and several applications on the contrary to lower carrier frequencies. In this study, the prominence of the 60 GHz frequency is explained with references to various studies, information from web pages, and publications. While offering faster data transfer compared to 4G and Wi-Fi signals, unfortunately, it has a shorter range. The effectiveness of 60 GHz is only applicable for unobstructed distances; the range decreases significantly in the presence of obstacles. Attenuation is another important issue, because of the oxygen at 60 GHz frequency, most of the signal is absorbed, so it is thought that it will be preferred more for indoor applications and wireless office communication. Technologic progresses continue rapidly, perhaps by increasing the number of sectors of base stations, beam forming technology or mesh networking between electronic devices the long distance issue can also be eliminated. In this study, an antenna design was also given after the review of 60 GHz and 5G, as a research side and it had –8.7 dB S11 value and 5.54 dBi gain. The designed micro strip antenna, particularly at 60 GHz, holds significant potential for various applications and contributes to the advancement of future communication technologies. Some potential applications include: 5G, wireless local area networks, indoor wireless communications, short range communication links, point-to-point and point-to-multipoint links, IoT, advancement in mm wave technology and so on with high data rate.

Keywords: Coplanar rogers 4350B, CST design, Multiantenna, V band, Wireless data transfer rates

Introduction

In order to transfer data wirelessly from one point to another point, a frequency value where the electronic system can operate is needed. While this transfer is being performed, speed is important and data must be sent intact. It is considerable that the frequency band to be used is clean or mint state. In the neighborhood of 60 GHz frequencies start to get importance from this point on. This frequency corridor is expected to be used because of being unlicensed, especially between 59–64 GHz (for Europe and 57–64 GHz for U.S, Canada, Brazil and Korea; the band width can change from country to country). The 60 GHz, which is in the range of 30–300 GHz, EHF (Extremely High Frequencies) band according to IEEE, also provides 5G communication technology. It is one of the frequencies where 5G operates (24–72 GHz; below 24 GHz for sub-5G). Antenna gain, EIRP (Equivalent Isotropic Radiated Power) and band width are also higher than 802.11b/g/n and UWB (Ultra Wide Band).[1–4]

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The 60 GHz frequency occupies a unique position in the EM (Electro Magnetic) spectrum, offering advantages.[5–7] These advantages can be listed as small wavelengths, directional antenna gain and reduced interference. These characteristics make it particularly valuable for applications like high speed data transfer, short-range communication and emerging technologies like 5G networks, wireless and VR/AR (Virtual Reality & Augmented Reality).[8–11]

The EM spectrum spans a wide range of frequencies, from ELF (Extremely Low Frequencies) and RF (Radio Frequencies) to microwaves, infrared, visible light, ultraviolet, X-rays, and gamma rays. In the EM spectrum, there are various applications in each frequency region, including radio broadcasts and communication, microwave ovens, remote sensing systems, thermal imaging, disinfection processes, medical imaging, radiotherapy, nuclear medicine etc.[5–8]

The speed of data transfer for 802.11ad gigabit wireless LANs (Local Area Networks) which use 60 GHz can reach up to 15 Gbps at a distance of 1 meter for indoor applications.[2,12] So why has this technology not been used so far? Because the costs were not as low as now, and MMIC (Monolithic Microwave

Integrated Circuit)[13] that makes circuit be in small size, high reliability, high productivity, high linearity, power efficiency, reliability, cost effective was not in today's sophistication.[1–3]

It is necessary to talk a little about defects. The biggest disadvantage of 802.11ad is attenuation. Oxygen absorption is at the highest level (98% of the transmitted RF energy) for 60 GHz in other words 5 mm wavelength. EM signals, which are already weakened by fog, dust cloud, water vapour and rain, become weaker as a result of the absorption of oxygen molecules. So, compared with other frequencies such as 2.4 GHz, path loss may become worse up to 30 dB. 22, 118, 183, 323 and 380 GHz are the other attenuation peaks but 60 and 120 GHz frequencies are more affected; this atmospheric attenuation is around 12 dB per km. Therefore, it is difficult to use it in the open area without connecting many transceivers to each other as a network structure or mesh. Consequently, this technology is feasible for local WAN (Wide Area Network) and in room apps like consumer electronics (audio-video streaming, multigigabit file transfer, home or office-campus utilizations, inter vehicle communication).

The barrier free environment should be still considered because attenuation for double glazed windows and concrete wall are between 3–7 dB and 20–30 dB respectively.

Absorption composes bad effects but interference is very less due to it. Oxygen and other gases clear EM waves, so frequency reuse range become higher. Different types of gases in the air, the amounts of these gases, factors such as rain, snow, fog, air pollution, reflections, absorption and signal decrease with distance are among the factors that cause EM wave (i.e. 802.11ad) attenuation.[1–3,14–18] Understanding and mitigating these factors are essential for optimizing the deployment of 802.11ad and other communication systems operating at 60 GHz. Techniques such as careful system design, beam forming, adaptive modulation, and error correction coding are often employed to enhance signal quality and overcome the challenges associated with attenuation at higher frequencies. V band (40–75 GHz) might be also used for communication between satellites in the earth orbit. Since there is not any gas in space at the geosynchronous altitudes (43,000 km).[19] By the way, the majority of communication satellites are located in the GEO (Geostationary Earth Orbit) region. The GEO orbit is situated beyond a distance of 36,000 km.[20]

In this article, information about some of the studies in the last decade using 60 GHz frequency or 5G frequencies is given in Table 1. The examination of 60 GHz and 5G technology has been thoroughly conducted through a review of previous studies, taking into consideration existing research findings.[36] It is learned from the statistics provided so far that bandwidth varies from country to country. It is also known that

Table 1 — Novel studies at 60 GHz, 5G frequencies

Purpose or Summary	Result	Key Findings and Contribution
Design and realization of the system and performance analysis with bit error rate (BER).[21]	60 GHz high gain antennas offer good solution about BER.	Enhances the understanding of antenna performance at 60 GHz in relation to BER, crucial for reliable communication.
For short range, line of sight, ultra high rate wireless communications, suppressing phase noise.[22]	Ultra high rate data transmission can be achieved with proposed receiver architecture.	Provides insights into overcoming challenges in achieving ultrahigh data rates for short-range, line of sight communication.
Point to point and point to multi point links, designing physical layer.[23]	Very high rate physical layer design can reach 1.3 Gbit/s for 9.7 m; 2.6 Gbit/s for 4.5m with Si-Ge technology.	Advances the understanding of physical layer design considerations for achieving high data rates.
To present channel sounder architecture and experimental study in Airbus 340 cabin.[24]	3 GHz band width, 50 dB dynamic range, 1 ns of delay resolution; a real time SIMO configuration.	Contributes to the understanding of channel sounder architecture and experimental setups in real world scenarios.
Segmented range detection method on linear frequency modulated & continuous wave mm wave radar.[25]	Higher range resolution and better noise performance when compared with digital signal processing method.	Advances understanding in radar technology, offering improved range detection methods.

(contd.)

Table 1 — Novel studies at 60 GHz, 5G frequencies (*contd.*)

Purpose or Summary	Result	Key Findings and Contribution
To investigate the feasibility of utilizing mm wave and terahertz bands for communication between UAVs (Unmanned Aerial Vehicles) and the data transfer characteristics at 60 GHz.[26]	Indicate successful data transmission between UAVs, demonstrating the capability to transmit 120 MB of data within approximately 500 milliseconds.	Contributes valuable insights into the potential applications of high-frequency communication in non-terrestrial networks, specifically beyond 5G.
To present balanced UWB dual polarized air interface architecture 0.25µm Si-Ge BiC-MOS chipset with low temperature co fired ceramics technology to get high resolution.[27]	7 GHz bandwidth, low cost, compactness, reliability and reproducibility. Phase adjustment at the RF stage, advantage for calibrations. Fully integrated phased antenna arrays.	Provides insights into achieving a balanced UWB dual polarized air interface with considerations for cost, size, and reliability.
Using rotatable highly directional horn antennas for both copolarized and crosspolarized antenna configurations to give the details of measurements that conducted in the 28–73GHz frequencies in an indoor environment for 5G.[28]	Time dispersion characteristics and large scale path loss models presented for mm-Wave channel models and systems. It can support IOT and 5G. Suggest the use of simpler and physically based path loss models.	Advances the understanding of antenna configurations and path loss models, particularly relevant for mm-Wave channel models and systems.
Designing and implementation a compact 1×8 array antenna which has 13.2 dB gain at 59.9 GHz.[29]	−10 dB return loss from 58.9 GHz to 60.9 GHz.	Contributes to the design of a compact array antenna with considerations for return loss, essential for efficient communication.
A review research about data centers which have wired or wireless technology.[30]	Hybrid techs can also be used in data centers at 60 GHz.	Enhances understanding regarding the suitability of 60 GHz technologies, both wired and wireless, for data center applications.
Analyzes were made for 5G wireless communication systems at various frequencies, i.e. 6 GHz and 60 GHz in meeting room, conference room and computer laboratory.[31]	All experiments were done for indoor applications. Power delay and power angle were studied.	Advances the understanding of 5G wireless communication in indoor environments, emphasizing power characteristics.
To use the positive effect of 60 GHz frequency on short distances in handwriting.[32]	Handwriting follow up is fast at this frequency.	Offers insights into the unique applications of 60 GHz frequencies, particularly in short range scenarios like handwriting recognition.
Microstrip antennas such as antipodal fermi Vivaldi antenna design have been studied on the LTCC substrate.[33]	Successful results have been obtained for the 60 GHz frequency in the ISM band. The cost is kept low.	Advances understanding in microstrip antenna design, particularly focusing on cost effectiveness for the 60 GHz frequency.
Gigabit wireless home techniques, connectivity, improving the connectivity by relaying and smart neighbor scanning are given in this thesis.[34]	It can be seen as a work to increase the connectivity value of 60 GHz technology, which is generally suitable for use in narrow spaces.	Contributes to understanding techniques for improving wireless home connectivity at 60 GHz, particularly in constrained environments.
The aim is to study propagation analytically, numerically and experimentally on body which is a skin equivalent phantom.[35]	The studies whose results are similar are done for vertical and horizontal.	Advances the understanding of signal propagation on the human body, considering both analytical and experimental approaches.

there is attenuation due to weather events.[18,37] At this stage, it should also be considered that there is no attenuation at certain specific frequencies. In studies related to behind the fog imaging, there is minimal attenuation at frequencies such as 35, 77, and 96 GHz, while it is considerably higher at other frequencies. It is also clear that 60 GHz and 5G technology has faster data transfer than Wi-Fi, or other mobile signal carrier frequencies. Consequently, it can be said that most of the studies are on frequency, attenuation and speed rate per second.

It should be noted that; during this study, not only 60 GHz projects were examined, but also 5G studies were given. The inclusion of 5G studies widens the scope and relevance of the research, as it allows for a holistic examination of advancements, challenges, and applications within the broader 5G ecosystem. This comprehensive approach contributes to a more

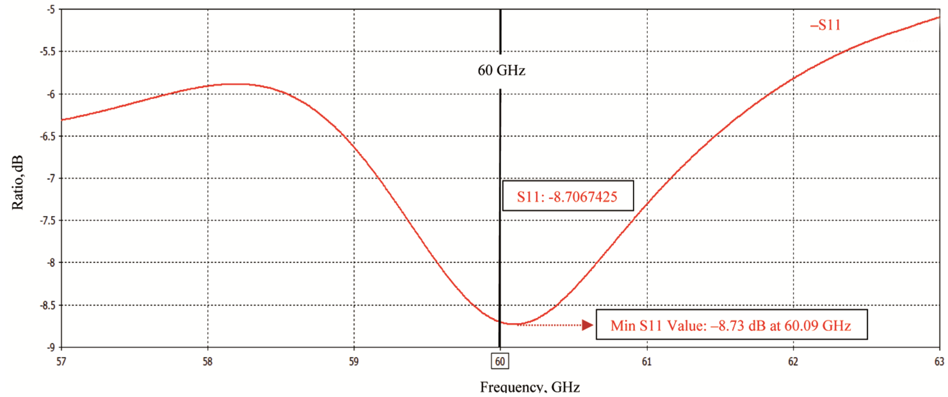

Fig. 1 — S11 Parameter of the designed microstrip Vivaldi antenna

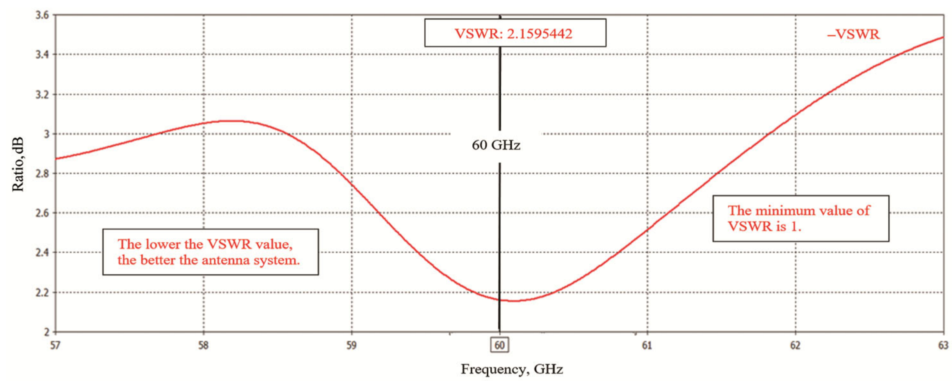

Fig. 2 — VSWR of the designed microstrip Vivaldi antenna

thorough understanding of the interplay between 60 GHz technologies and the overarching 5G framework.

Materials & Methods

Lossy FR-4 and lossy Rogers 4350B substrates were used for the experiment. Vivaldi design was chosen. The aim of selecting a Vivaldi antenna is to achieve wide bandwidth, high gain, and directional radiation patterns. The antenna was designed at CST Studio Suite Program for accurate modeling, simulation, and optimization of the antenna's performance. Antenna geometry, antenna dimensions, substrate material, feed point location, transmission line characteristics, matching network components, tuning elements, frequency of operation, radiating element design, ground plane design, simulation and optimization tools can be counted as key parameters of the design.

The designed microstrip antenna at 60 GHz addresses the challenges associated with this frequency through careful consideration of several key factors. Firstly, the compact size and planar structure of microstrip antennas make them suitable for high frequency applications, allowing for ease of integration into devices. The antenna's geometry and design parameters are optimized to achieve the desired performance at 60 GHz, considering factors such as antenna size, substrate material, and feed configuration.

S11 (Scattering 11) parameter of the antenna is shown in Fig. 1 from 57 to 63 GHz frequencies and its value is –8.7 dB at 60 GHz, middle of the frequency range. The minimum S11 value which is –8.73 dB is at 60.09 GHz.S11, also known as the reflection coefficient, quantifies how much of the incident power is reflected back from the antenna due to impedance mismatches.

A lower S11 value indicates better impedance matching, meaning that more power is efficiently transferred from the transmission line to the antenna, resulting in improved performance. Achieving and maintaining a low S11 value is vital for optimizing the antenna's performance in the context of 5G and high frequency electronic communication systems.

The VSWR (Voltage Standing Wave Ratio) value is 2.159 at 60 GHz, it is given on Fig. 2. The VSWR value of the microstrip antenna at 60 GHz is a critical

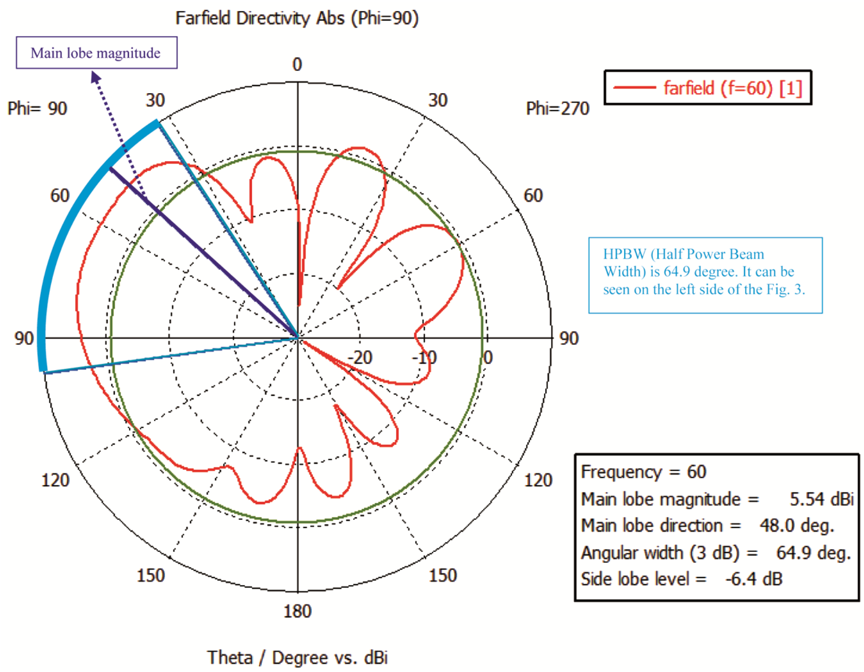

Fig. 3 — Farfield radiation graph of the designed microstrip Vivaldi antenna

parameter that directly influences its performance. VSWR measures the efficiency of power transfer between the antenna and the transmission line. A low VSWR indicates a good impedance match, minimizing signal reflection and maximizing power transfer. A high VSWR could result in increased signal reflection, leading to a mismatch between the antenna and the transmission line. This mismatch can cause degradation in the antenna's performance, resulting in reduced efficiency and potential signal loss. Therefore, maintaining a low VSWR at this frequency is essential for optimal antenna performance in 5G applications.

The farfield radiation graph with the polar coordinates is represented in Fig. 3. The main lobe magnitude is 5.54 dBi at 60 GHz. Between 60 degree and 120 degree at Phi axis and between 45 degree and 75 degree at Theta axis have good directivity values. Regarding the farfield radiation graph, it provides insights into the antenna's directivity, indicating how well the antenna focuses its radiated power in a specific direction. The shape and characteristics of the farfield radiation pattern reveal information about the antenna's ability to concentrate energy in the desired direction and minimize radiation in undesired directions. Analyzing the farfield radiation graph helps assess the antenna's suitability for directional communication and its performance in real world applications.

The components and the full view of the Vivaldi microstrip antenna with some of the dimensions are mentioned as perspective view in Fig. 4. The designed microstrip antenna has diverse potential applications, ranging from supporting 5G networks to facilitating highspeed wireless communication in various environments. Its contribution lies in advancing the capabilities of future communication technologies, particularly in terms of data rates, low latency, and the efficient use of high frequency bands.

The properties of the materials which are lossy FR-4 and Rogers 4350B are also shown at the left side of the Fig. 4. The choice of materials for the microstrip antenna involves a tradeoff between dielectric properties, cost, and specific design requirements. The use of lossy FR-4 and Rogers 4350B substrates allows for tailoring the antenna characteristics, optimizing performance, and meeting the demands of the targeted application in the field of microstrip antenna design for electronic communication engineering. Lossy FR-4 substrate advantages are the increased loss tangent for better impedance matching and reduced surface wave propagation, which can enhance the antenna's radiation efficiency. It also helps in controlling the bandwidth and achieving desired characteristics. Rogers 4350B substrate advantages are the low loss tangent that minimizes signal attenuation, contributing to improved radiation efficiency. Its

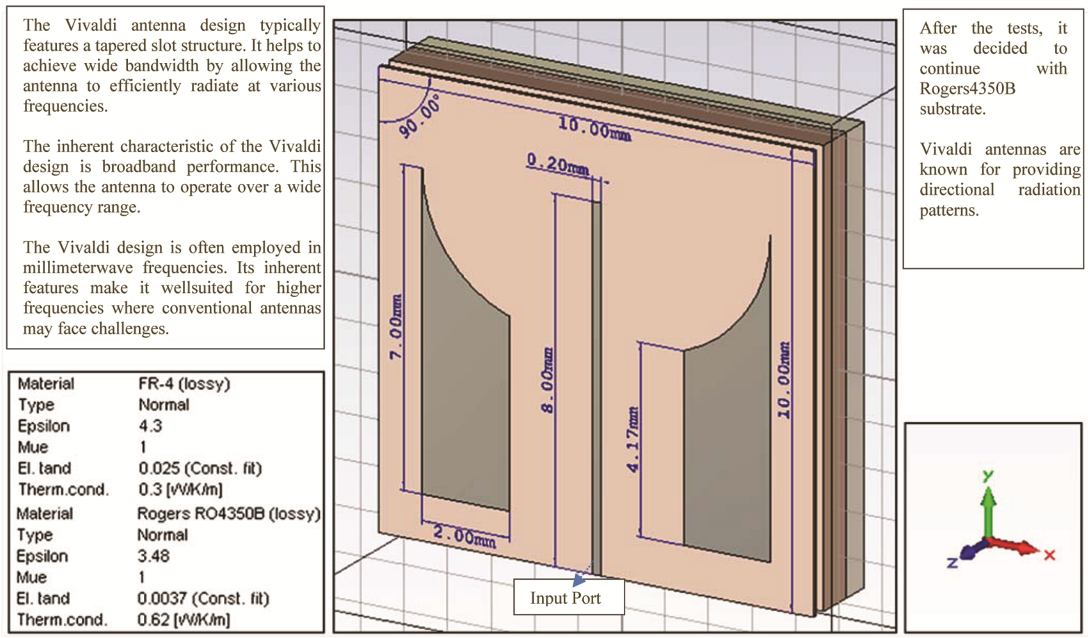

Fig. 4 — The designed microstrip Vivaldi antenna and substrate specifications

stable dielectric constant ensures consistent performance over a range of frequencies.

The directions can be seen at the right side of the Fig. 4. There is a PEC (Perfect Electrical Conductance) material that has 0.7 mm thickness at the back side of the microstrip Vivaldi antenna in the middle of the shape.

Results &Discussion

The research findings regarding the designed microstrip antenna, especially in the context of 5G technology, have several implications such as enhanced data rates, low latency, short range, high capacity link, indoor and localized connectivity, contribution to millimeter wave, efficient spectrum utilization, innovation in antenna design, path for future research and development in high frequency applications.

After some previous studies were given, an antenna that could operate on 60 GHz middle frequency has been designed. Its S11 value was under –8 dB and according to simulations it could be used for indoor applications. Its VSWR value was 2.15 and this value was considered sufficient for the antenna. This tiny 1cm square antenna was simulated on frequency domain and had 90 degree polarization angle. It might be developed efficiently in the next designs. As the frequency increases, and consequently the wavelength decreases, it becomes possible to perform operations with more miniature designs. Therefore, it becomes clear that electronic circuits antennas operating at 60 GHz frequency or 5G frequencies are better in terms of speed, but the communication distance is narrow due to the attenuations.

The main lobe direction of the designed antenna has been measured at 48 degrees with a gain of 5.54 dBi. The bandwidth, defined as the HPBW (Half Power Beam Width) between directions where the gain drops by 3 dB, is determined to be 64.9 degrees. The design emphasizes directional antenna characteristics. Side lobe levels are observed at –6.4 dB.

According to previous studies given in Table 1, millimeter wave applications are increasing in 5G, 60 GHz frequency and their surroundings. Antenna designs, power amplifiers, LNAs etc. are some of the areas where millimeter wavelengths are used. Additionally, its availability has gained importance due to the increasing demand for band width intensive applications, such as high definition video streaming, VR/AR. The 60 GHz frequency enables the deployment of high capacity and short range communication links, contributing to the overall efficiency and performance of 5G networks.

It is evident that advancements in materials and electronics technology, coupled with the reduction in transistor sizes, will lead to improved works. Fig. 5 illustrates the provided process flow chart.

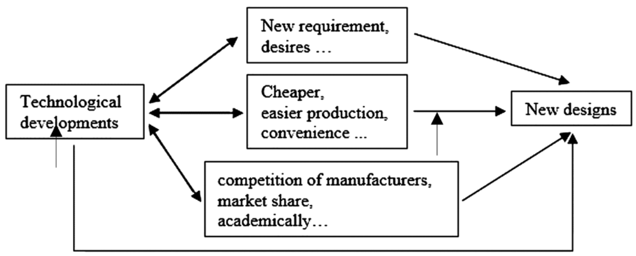

Fig. 5 — The flow chart of process

Conclusions

Even though coplanar antennas in 60 GHz frequency as in the article are more likely to work indoors and have low ranges, they will be still preferred in the near future because they are faster than previous generations.

The 60 GHz frequency is considered suitable for indoor applications primarily due to its unique characteristics and advantages. One key feature is the high oxygen absorption rate at 60 GHz, which results in lower signal propagation through walls and other obstacles. This characteristic makes the 60 GHz frequency well suited for indoor environments, as it helps minimize interference and allows for more secure and confined communication.

The FR-4 is not suitable for the high frequency operations, it will be better to use only Rogers 4350B sub strate in this work because of being a high frequency laminate material known for its low dielectric loss, high thermal conductivity, and stable electrical properties.

The future scope of this research involves further exploration and optimization of the designed microstrip antenna for enhanced performance and applicability in 5G technology. Subsequent designs could focus on refining the antenna's characteristics, improving data rates, and extending communication distances while maintaining low latency. Future studies may explore into the development of miniature designs operating at 60 GHz or 5G frequencies, exploring innovations in antenna design and efficient spectrum utilization. Additionally, investigations into alternative substrate materials, such as flexible substrates, could be pursued for better performance in high frequency operations.

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