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Microstrip Patch Antenna with C Slot for 5G Communication at 30 GHz

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Abstract

A novel design of a 30 GHz microstrip line-fed antenna for 5G communication has been presented in this paper. 5G is the latest industry standard in mobile communication, which is designed to deliver higher data speeds, lower latency, greater network capacity, and higher reliability. It uses major parts of the mmWave spectrum (28 GHz to 40 GHz), allowing for a wide range of applications like mobiles, vehicles, medical devices, and other IoT networks. This mmWave network requires efficient antennas for its effective communication. Patch antennas use the function of oscillating their physical structure to the wavelength of the transmitting wave. Thus, higher efficiency can be achieved in the mmWave spectrum due to its proximity to the actual dimensions of the patch antenna, which also allows us to design antennas at small sizes and high reliability. The design in this report has a patch antenna with a centre frequency of 30 GHz. The antenna was optimized for this frequency based on the best reflection coefficient and gain while keeping the restraints of staying within the FR-2 band of 28 GHz to 33 GHz. The proposed antenna has been implemented using Rogers RT5880 substrate for high gain and performance across a wide range of frequencies. The feed is also accompanied by a quarter-wave feed cut for performance increase and impedance matching. The design has a gain of 8.45, with a reflection coefficient of -8 dB at a resonant frequency of 30 GHz. It shows great directivity of 5o and VSWR of 2.3 over a bandwidth of 3.5 GHz. It also employs a 0.4 mm C slot, which induces a dipole effect, thereby increasing the directivity and gain of the antenna. Hence, it is recommended for use in applications related to 5G mobile communication.

Keywords:

Patch Antenna;
Microstrip; 5G;
Radiation Pattern;
Gain; VSWR;
C Slot;
Reflection Coefficient.

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1- Introduction

Communication is an integral part of society, from the smallest scales of daily human communication to intercontinental communication across vast oceans. Telecommunication technology achieves this using radio waves transmitted either through land-based antennas or geostationary satellites orbiting Earth. With the introduction of cellular communication, handheld devices have become commonplace and require fast, dependable, and stable connections to the rest of the telecommunication network. Cellular networks satisfy these requirements by distributing multiple cells over the coverage area, within which each cell supplies an area with a fixed transmitting and receiving tower with an antenna. All mobiles within this cell communicate to this fixed tower and through the tower to the rest of the world [1].

The link between the mobile device and the tower is the primary point of contact for users with the network, thus making it the most critical component to optimize. Each cell has a dedicated bandwidth within which users are assigned smaller sections to use as needed. Every decade, the telecom industry upgrades its networks, beginning with 3G in the

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early 2000s, 4G in the early 2010s, and the industry's recent transition to a 5G standard. The main promise of this improvement is higher speeds and lower latency, allowing for faster and smoother communication. 4G offered real-world speeds of 35 Mbps, and 5G offered an improvement of 50 Mbps [2]. The primary improvement is the lower time delay between two points for packet transmission, also called latency. The latency for 4G was at 50 milliseconds, while 5G has a latency of just one millisecond. 5G is a significant advancement over its predecessor [3]. 5G has a broad range of applications, including mobile communication, connectivity for the Internet of Things, and mission critical communications such as satellites and remote vehicle control, to name a few. Additionally, it enables higher speeds, higher bitrates, and larger bandwidth by using the mmWave spectrum, allowing for the connection of more devices [4]. The industry has two allocated spectrums for 5G communication. These two spectrums are FR1 and FR2. FR1 operates at frequencies less than 6 GHz while FR2 operates at frequencies greater than 6 GHz. Within these spectrums, various sections are assigned in accordance with applicable telecommunication laws and availability. Figure 1 shows a general overview of the frequency bands [5].

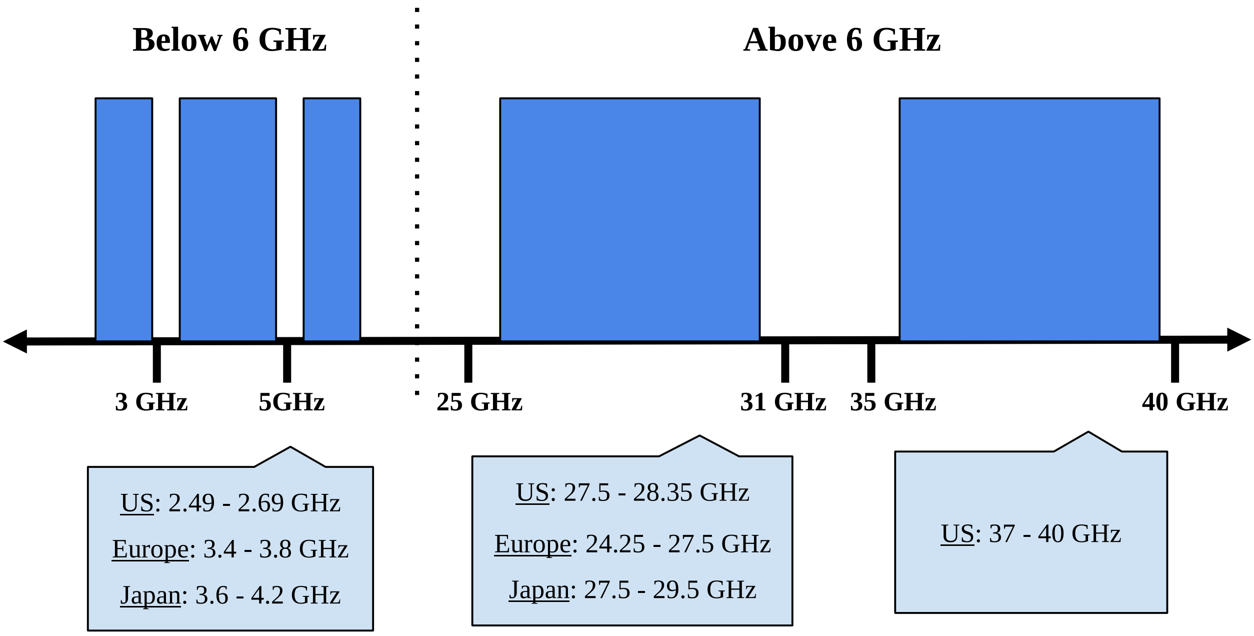

Figure 1. Overview of 5G Frequency Bands

A lot of work has been done on patch antennas operating for 5G communication within the FR1 band. However, not much literature is present for patch antennas within the FR2 band. Furthermore, the implementation of slots within the patch antenna allows for improved results as well as increases the design's applications. The design implemented within this paper is a novel C slotted configuration that allows for the accommodation of dipole fields to enhance the patch field to produce an antenna with better gain, directivity, and bandwidth.

2- Patch Antenna Theory

Antennas are essential for all forms of mobile communication, and the type of antenna is highly dependent on the application. Patch antennas are small dimensioned antennas with a low profile typically used when size and compatibility are critical. They are composed of two metal sheets, one of which is grounded with a substrate sandwiched in between. The two metal sheets combine at specific wavelengths to form a resonant transmission line with high gain and permeability. Moreover, it is quite simple to construct and use printed circuit boards with extremely high accuracy at a low cost. As the physical dimensions of the patch resonate within the mmWave band, they can be fabricated at smaller dimensions than other radio antennas making it perfect for 5G communication [6, 7].

Patch antennas are constructed by sandwiching a substrate between two metal sheets of copper, one of which is grounded, as illustrated in Figure 2. Based on the requirement, the patch's dimensions can be rectangular, triangular, circular, and so on, each with its own transmission properties. Additionally, certain shaped cut-outs can be introduced to increase gain and facilitate the formation of dipoles. Parasitic sections can be added to improve directivity further. Different substrates can also change the functioning of the patch based on the height and dielectric constant. Each component of the patch antenna must be chosen with care to meet requirements [8].

The geometry of the patch allows for the formation of a standing wave when current flows through the patch. Thus, the frequency must exactly match the geometry of the patch, namely the length, to ensure maximum efficiency. The width of the patch determines the line impedance produced by the patch towards the transmission line.

The geometry of the patch allows for fringing fields to form along the width and the substrate allows for direction to be set along the Z axis. As they use very thin sheets of metal, they generally have high gain and require low power to operate due to the skin depth effect of metals. Since their dimensions are dependent on the resonating frequency, the parameters such as substrate height, feed length, and feed type are used to optimize the antenna's performance. The various types of feeds are determined by the impedance requirement, size constraint, and current supply [9].

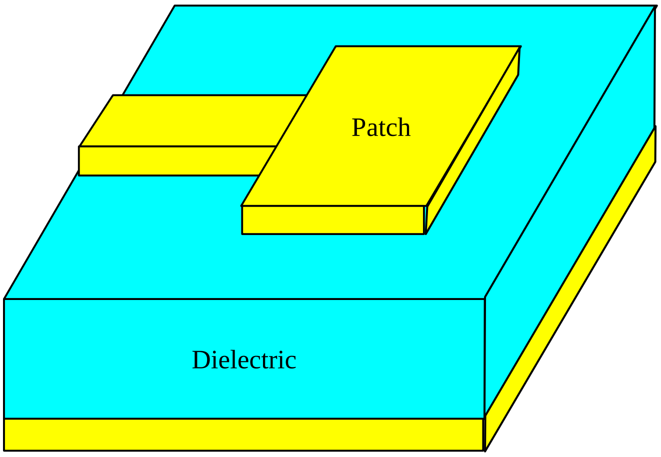

Figure 2. Patch Antennas Structure

3- Literature Review

Chandra et al. [10] described the evolution of wireless communication and mobile handsets and further went on to the characteristics and several types of antennae. They also described the different frequency bands and the requirements of modern wireless communication. Kiran et al. [11] explained the several types of wireless communication over the years and the allocation of new frequency bands for 5G communication. The authors highlighted the need for miniature antennas, how microstrip antennas function, and their benefits and structures. Cheekatla et al. [12] classified the differences between 4G and 5G communication while highlighting the higher data requirements of upcoming technologies. The researchers showed how 5G communication would solve this problem using millimetre wave frequencies. Ramli et al. [13] showed the benefits and demerits of 5G communication, along with the industry standards for certain countries. The paper reported how patch antennas are the best way to address these problems due to their design benefits and low cost. Yon et al. [14] presented the merits and demerits of microstrip antenna together with the ways to increase their effectiveness in 5G communication with structures such as parasitic patches, arrays and loaded antennas. Abedin et al. [15] explained the structure and functioning of mobile communication in addition to the different types of patch antennas, going into detail about their radiation patterns and polarization. The structure and operation of 5G communication were explained as well. Al-Kharusi et al. [16] explained in detail the composition and structure of patch antennas in addition to their determining factors. The benefits of introducing air gaps within the substrate to improve performance and how it influences the gain and bandwidth were discussed. Kumar et al. [17] underlined the changes in electronics and mobile communications, with the antennas needing to be small, low cost and broad bandwidth. They went on to show how patch antennas are the ideal antenna for this specification, with the restrictions on their dimensions and materials. Bhunia [18] listed out the applications of patch antennas and how their performance can be improved through modification of radiating patch and improvement of bandwidth. Ojaroudiparchin et al. [19] investigated the history of 4G communications and discussed the improvements of 5G being brought into the industry. An emphasis on the requirements 5G antennae are now facing with lower costs, smaller dimensions, and higher gain was made.

Palanivel Rajan et al. [20] called attention to the popularity of patch antennas and the methods to navigate the disadvantages of patch antenna. The authors further reported their design in detail. Wang et al. [21] defined the structure and modes of excitation of their design. The researchers highlighted the results they obtained accompanying with describing the fabrication process of their prototype. Islam et al. [22] detailed the dimensions and components of their design besides the type of feed, frequency region and modifications done to traditional patch design. The authors specified the results obtained from both simulation and measurements together with the application of their design. Colaco et al. [23] called attention to the need for efficient antennas in the rapidly growing regions of the world and listed the applications of their design. The parameters of their design in company with the software used for their simulations and results obtained through these simulations were identified. Punith et al. listed the applications of 5G in the field of space research and connected the benefits patch antennas have when used as multi-band antennas. Punith et al. detailed their results on top of the operating frequencies [24]. Ponnapalli et al. [25] went into detail about their design and the orientation of their slot. The researchers stated the operating frequencies and substrate being used in addition to the application of their design. Darboe et al. [26] described their design structure and the dimensions. They set down the operating frequency accompanying with the results they obtained through simulations. Lodro et al. described their design's resonant frequency and bandwidth. Lodro et al. emphasized on the features of the design including its dimensions and results obtained through simulation [27]. Kim et al. went into detail about the structure and components used in their design, namely the substrate and the cavity inserted. Kim et al. reported the dimensions of their design plus the results obtained such as cross polarization, gain and envelope correction coefficient [28]. Islam et al. [29] stressed on the need for design improvement in the field of breast cancer detection and how their design has been optimized for that requirement. They spelt out the frequency of operation and the parameters being used for the simulations inclusive of the results such as bandwidth, radiation efficiency and return loss, obtained through the simulations.

Information regarding the type of antenna being designed coupled with the type of feed being used was given. Information about the substrate and its physical properties was cited. The dimensions of the patch were detailed to go with the geometric additions such as adding slots, parasitic patches or stubs and substrate improvements such as air gaps, radiators and double layers were listed. Results such as resonant frequency, gain, reflection coefficient, VSWR, etc. were also specified.

The results of these papers contained detailed descriptions of simulations on software. The data shown included but not restricted to S11 parameters, gain, VSWR, bandwidth, impedance, etc. The results also included graphs showing directivity, radiation pattern, magnetic field, electric field, surface current, port information, etc. The results contained tables comparing results of assorted designs within the paper and of those from reference papers. It also had information regarding the results from other papers for comparison.

The literature survey displayed a gap in designs in the FR2 region for slotted patch antennas. This is the main region of operation for 5G devices, and the usage of slots will greatly enhance the functioning of IoT devices. Thus, the design proposed in this paper aims to satisfy this requirement.

4- Problem Statement

The aim of this paper is to design an antenna to function in the 30 GHz frequency range for 5G mobile communication with high gain and low reflection coefficient. A novel C slot is to be introduced as the radiation is increased to allow for greater gain.

5- Design of Proposed Patch Antennas with Rectangular C Slot

The patch antenna shown in Figure 3 functions as a voltage radiator, which is a structure that emits radiation in response to a voltage difference, in comparison to a wire antenna, which functions as a current radiator. When a current is passed through the patch antenna, the antenna's physical dimension allows for the formation of a standing electromagnetic wave within the substrate. This results in a voltage differential between the antenna and the ground plane which results in the fringing of the electric fields within the lengthwise ends of the antenna. Due to the direction of the fields at the surface (in the '+ve y'), the antenna is able to radiate in that direction. In addition, the fringing fields increase the patch's effective radiating area, thus a patch with wider width will radiate more, but at the same time would draw more power [11].

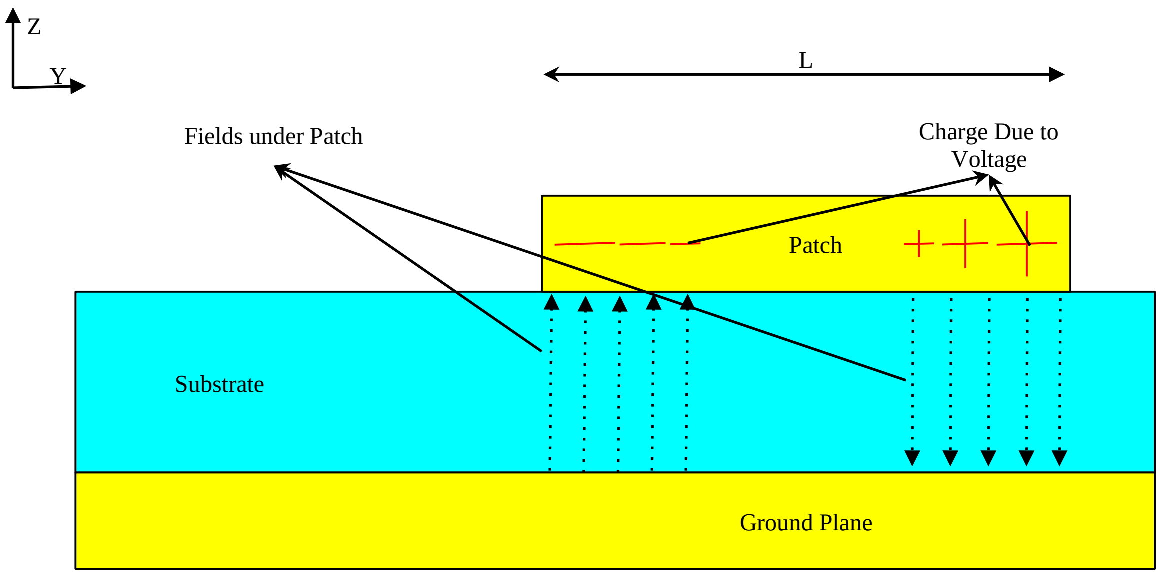

Figure 3. The Operation of Patch Antennas

As the physical dimensions of the patch are critical to the antenna's operation, both the width and length must be chosen carefully. Due to the formation of a standing wave, the length dictates the frequency to be used. As the fringing fields increase the effective length of the radiator, the theoretical value is always slightly greater and must be compensated for. The width of the antenna determines the input impedance, bandwidth, and radiation pattern of the antenna. Thus, a width must be chosen that balances these parameters effectively.

The design is first implemented on CST Microwave Studio using the initial parameters from the equations. After analyzing results and comparing with previous results, the dimensions of the design are changed to obtain better values. After multiple iterations of this cycle, the optimal values for width and length are found. The design procedure is displayed in Figure 4.

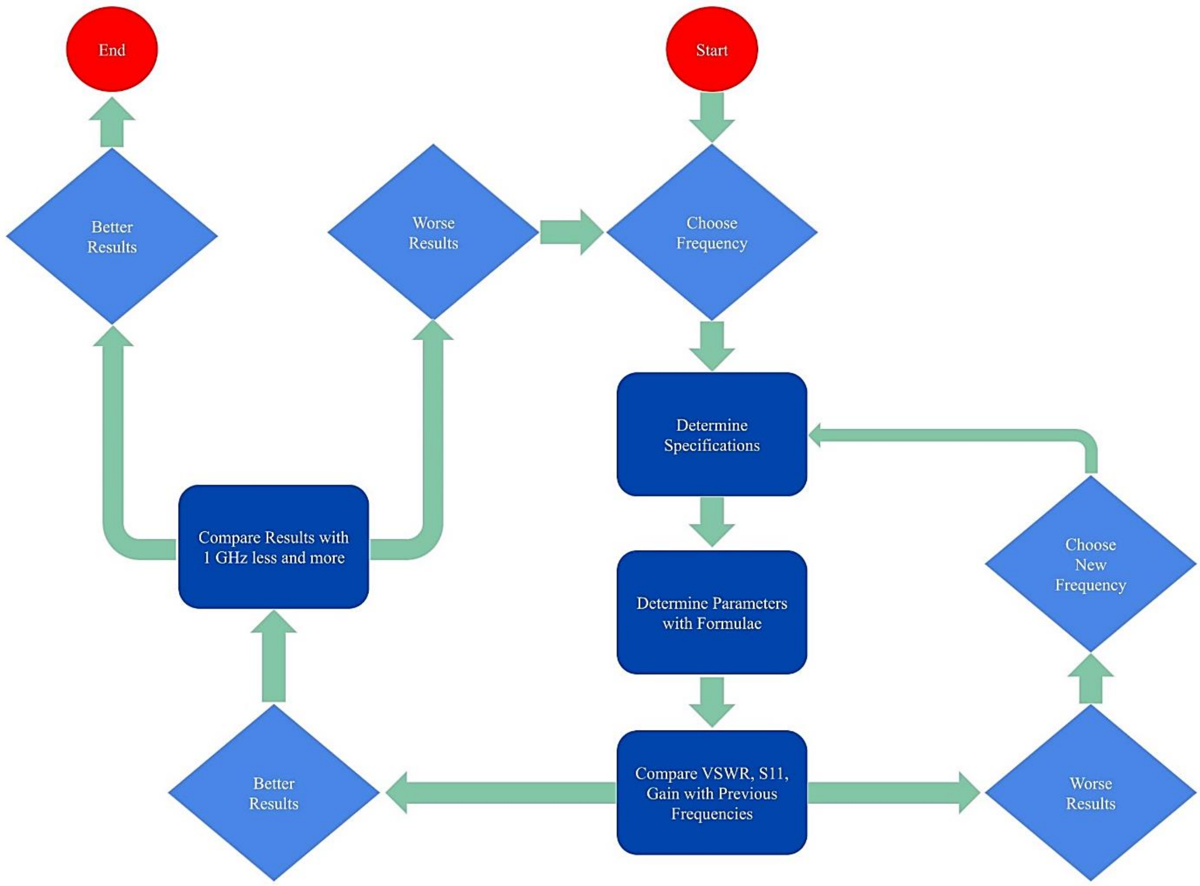

Figure 4. Flowchart of Design Process

Using both transmission line analysis and cavity model analysis, formulae for the width, length and feed length are specified [30]. The formula for patch width is as follows, where 'f_o' is the operating frequency, 'ε_r' is the dielectric constant of substrate [30].

$$Width = \frac{c}{2f_o\sqrt{\frac{\varepsilon_r+1}{2}}} \tag{1}$$

The formula for patch length requires the effective dielectric constant given by 'ε_{eff}' whose formula is as follows, where the width of the patch is 'W', and the substrate height is expressed as 'h' [30].

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[\frac{1}{\sqrt{1+12(\frac{h}{W})}}\right] \tag{2}$$

The length is calculated using the following formula [30]:

$$Length = \frac{c}{2f_o\sqrt{\varepsilon_{eff}}} - \left(\frac{(\frac{W}{h}+0.264)(\varepsilon_{eff}+0.3)}{(\frac{W}{h}+0.8)(\varepsilon_{eff}-0.258)}\right)0.824h \tag{3}$$

The feed length is calculated using the following formula, where 'Z_o' is the target impedance, 't' is thickness of ground [30]:

$$w = \frac{7.48h}{exp\left[Z_o\cdot\left(\frac{\sqrt{\varepsilon_r+1.41}}{87}\right)\right]} - 1.24t \tag{4}$$

Another critical parameter to take account of is the patch antenna's impedance. The standard impedance of a transmission line is 50 Ohms. However, when designing an antenna, the impedance may differ, and impedance matching must be performed to prevent power loss due to a mismatch. For a patch antenna this can be done either through an inset or a quarter wave feed. As the design in this paper already includes slots, insets would compromise the radiation pattern and thus a quarter wave feed has been introduced. The quarter wavelength feed enables to correct any mismatch between the load and transmission line. An ideal transmission line would have a line and load impedance that are matched. It accomplishes the matching by reflecting the wave with a 180o phase difference, thus clearing the transmission line of waves causing mismatch. The quarter-wavelength feed formula is as follows [30]:

$$Z_o = \sqrt{Z_{in}(\lambda/4) \cdot Z_l} \tag{5}$$

5-1- Specifications of Proposed Antenna

The proposed antenna, as portrayed in Figure 5, is determined by the resonant frequency, substrate type and height, impedance, quarter-wavelength feed, and thickness of ground all of which are specified in Table 1.

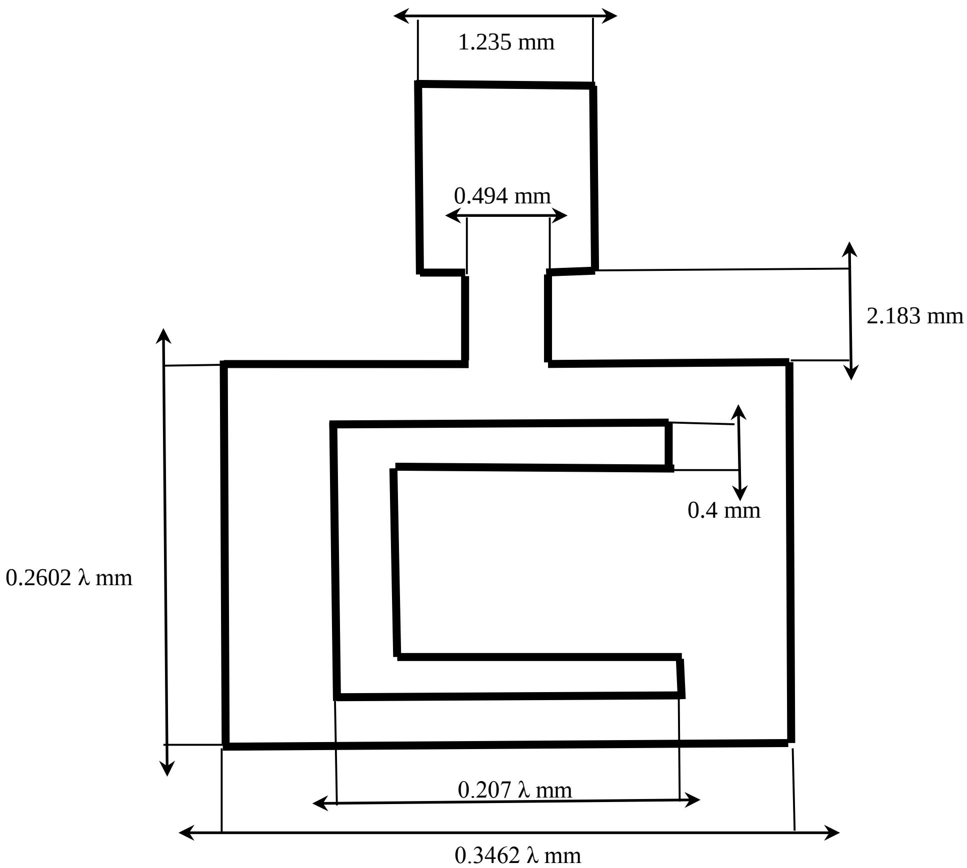

Figure 5. Proposed Patch Antenna with C Slot

Table 1. Design Specifications of Proposed Antenna

Parameter	Value
Ground Thickness	0.032 mm
Impedance	50 Ohms
Resonant Frequency	34.33 GHz
QW Feed Length	2.183 mm
Dielectric Constant	2.2
Height of Substrate	0.508 mm
Size of C Slot	0.4 mm

- The thickness of ground and patch are determined by an effect called skin depth, in which the current flows only on the surface depending on the wavelength [31]. Subsequently, convention determines the thickness to be '0.032 mm'.
- The impedance was matched to '50 ohms' which is the most frequently used impedance matching.

- The resonant frequency was chosen as '34.33 GHz' because there is a reduction in resonant frequency after introduction of a slot [32]. This increase in initial frequency would compensate for the decrease in resonant frequency and bring it back to the required value.
- The quarter-wavelength feed is thus '2.183 mm'.
- 'Rogers RT Druid 5880' was chosen as the substrate due to its uniform electrical property over a wide frequency range, high gain, and low loss [33]. The substrate's height is taken as a value between an upper and lower limit defined by the resonant frequency, given as [30]: $0.003\lambda_o \leq h \leq 0.05\lambda_o$.
- The size of the C slot had to be chosen carefully to ensure that the dipole effect occurred without impairing the gain or reflection coefficient. The ideal value was found to be '0.4 mm'.

5-2- Design Parameters of Proposed Antenna

With the formulae and design specifications, the patch dimensions are shown in Table 2.

Table 2. List of Parameters

Parameter	Value
Width of Patch	3.452 mm
Length of Patch	2.602 mm
Width of Feed	1.235 mm
Width of QW Feed	0.494 mm

6- Results by Simulation of the Proposed Antenna

6-1- Performance of Reflection Coefficient

Figure 6 is a representation of the performance of the reflection coefficient, also known as the S11 parameter. Simply said, the reflection coefficient is calculated by dividing the amount of power that is reflected by the total amount of power that is applied to the antenna. Therefore, antennas with lower S11 values are considered to work better than those with higher levels. In addition to that, the graph of S11 vs. Frequency illustrates the design's resonant frequency additionally to its bandwidth. We were able to calculate that the resonance frequency is 30 GHz, and the reflection was found to be -8.05 dB. The bandwidth at a dB level of -3 was found to be 3.5 GHz, which is within the ideal range. The arc is uninterrupted by any leaps or gaps in continuity, giving it a smooth look. The reflection coefficient is -2 dB at 28 GHz, gradually rising to -5 dB at 29 GHz, and then reaching -8 dB at 30 GHz before plateauing. The curve mirrors at the resonant frequency with an S11 of -5 dB at 31 GHz and with a S11 of -3 dB at 32 GHz. The lack of jumps or breaks indicate that the design can function well within the bandwidth of 3.5 GHz.

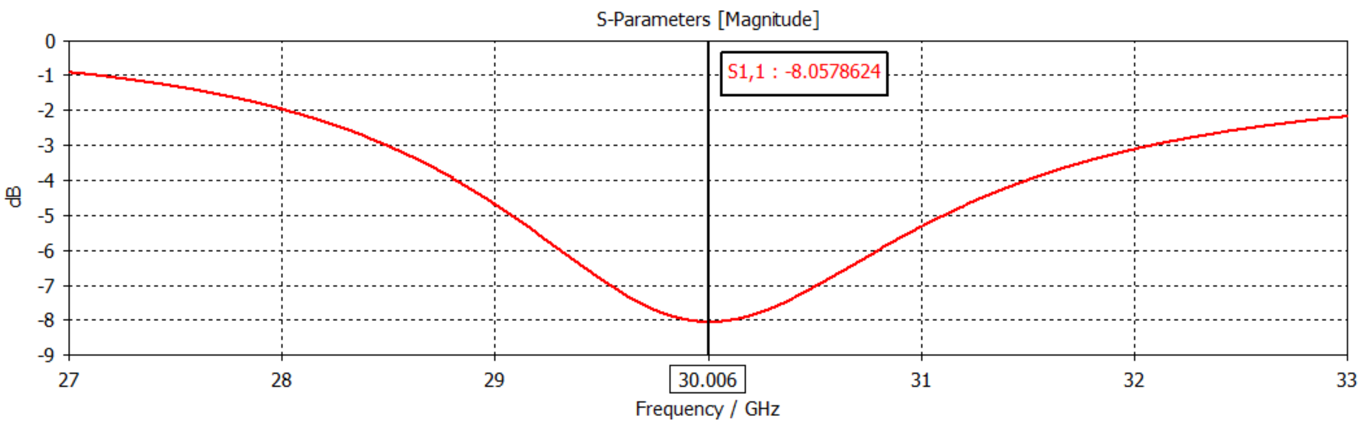

Figure 6. Reflection Coefficient (S11) Graph

6-2- Performance of Gain

Figure 7 provides a visual representation of the gain performance of the proposed antenna in relation to frequency. A resonance frequency of 30 GHz was used to determine the gain, which was determined to be 8.45. It has been shown that gain increases at a constant rate over the frequency range, with a maximum variance of 1 across the frequency bandwidth. The gain is highest at 29 GHz, with a value of 8. The gain is lowest at 28 GHz, with a value of 8. The gain has a value of 8.4 in the middle range when measured at the resonant frequency of 30 GHz. At the maxima of the bandwidth (32 GHz), the gain reaches a value of 9.2. Although the gain is highest at 32 GHz, the VSWR and S11 parameter are determined to be at their best at 30 GHz; hence, this frequency is modelled as the resonant frequency. Furthermore, the maximum variance of 1 across the bandwidth implies that the design can produce similar gains throughout the bandwidth.

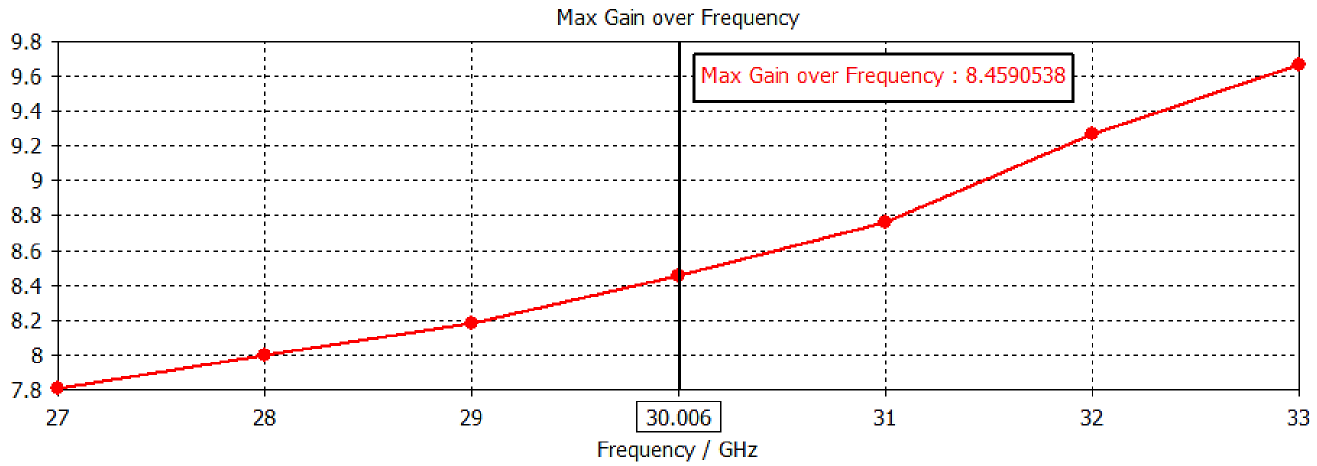

Figure 7. **Gain Performance vs. Frequency**

6-3- Radiation Characteristics of the Proposed Antenna

The part of an antenna known as the farfield, which is often referred to as the radiating region, is the part that is taken into consideration for long-range antenna transmission. Electromagnetic (EM) waves exhibit typical behaviour in the farfield area, with orthogonal electrical and magnetic fields in the direction of propagation. The term "directivity" refers to the ratio of radiation in one direction to the overall average radiation in all directions. It is a term that refers to the capacity of an antenna to transmit in a certain direction. Figure 8 displays the farfield radiation pattern at a frequency of 30 GHz. As pictured in Figure 8, the red graph depicts the directivity in different angles of θ with the maximum around θ=0° and decreasing as you move away. The main lobe is at a 5° from θ=0 and is the optimal direction for transmitting with highest directivity. It exhibits highest directivity at 5° with an angular width of 61.9° over the bandwidth. The high angular width implies that the C slot fields are increasing the overall transmission area of the patch when compared to a traditional patch design.

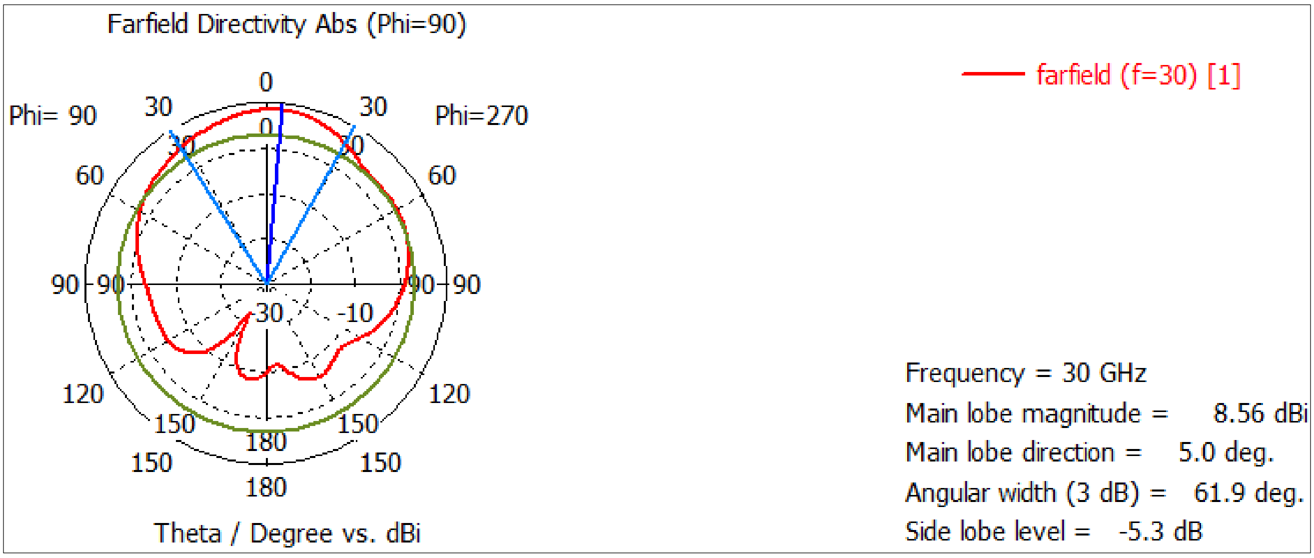

Figure 8. **Radiation Pattern Polar**

The directivity graph around θ with φ=0° offers an indication of the form of the main lobe, and the concentric circles give an indication of the gain in terms of maximum directivity. Figure 9 shows the top cross-sectional view of the farfield radiation. Figure 9 shows that design's directivity is best around θ=0° and it decreases around θ=5°. Because of the existence of the feed line, there is relatively little power that travels in the reverse direction. This is typical behaviour for antennae. However, the design displays great horizontal directivity, except in the direction of the feed line.

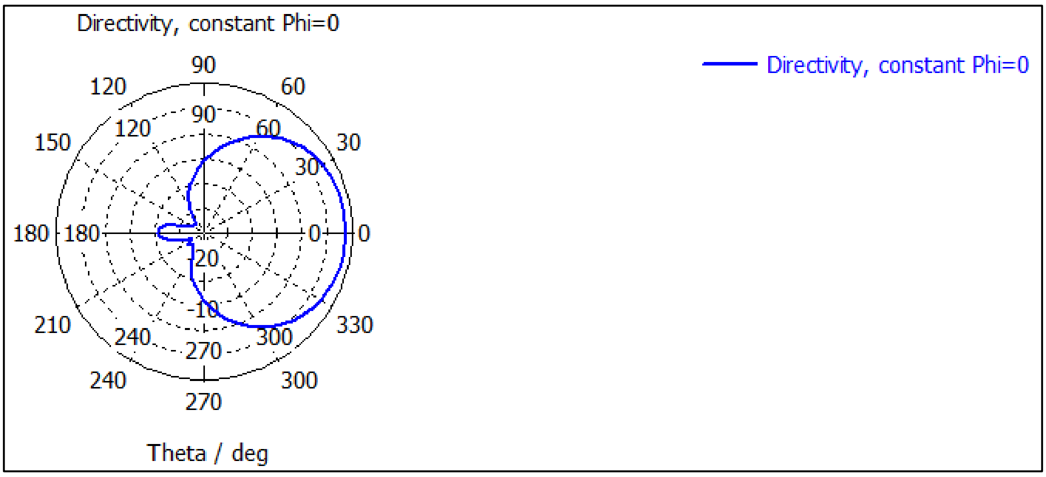

Figure 9. Radiation Pattern Front Lobe

Figure 10 portrays the front cross-sectional view of the farfield radiation pattern. The directivity graph shown in Figure 10 around φ with θ=90º indicates the shape of the side lobe, while the concentric circles give the size in terms of maximum directivity. The lobes are placed in the top to bottom and side to side regions, highlighting the best directions for transmission. The design can cover a significant amount of the vertical space which is a result of the addition of the C slot fields.

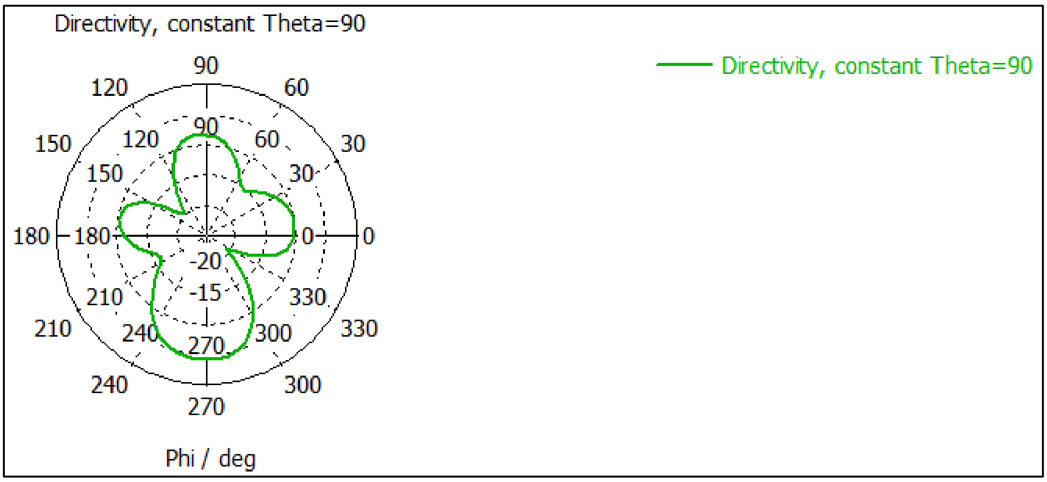

Figure 10. Directivity Performance Graph

Figure 11 presents, the heatmap that indicates the gain is 8.57 dB when the angle is equal to zero and declines to -9.6 dB when the angle is equal to 180 degrees. This indicates that the antenna transmits most effectively near the value 0 and that its effectiveness decreases as you travel farther away. The directivity in the red parts is the greatest, coming in at 8.57 dB, while the directivity in the green areas is the average, coming in at – 9.61 dB, and the directivity in the blue regions is the lowest, coming in at -31.4 db. As can be observed, the "positive Z" direction contains a significant amount of red, which indicates that it exhibits the highest level of directivity in this direction.

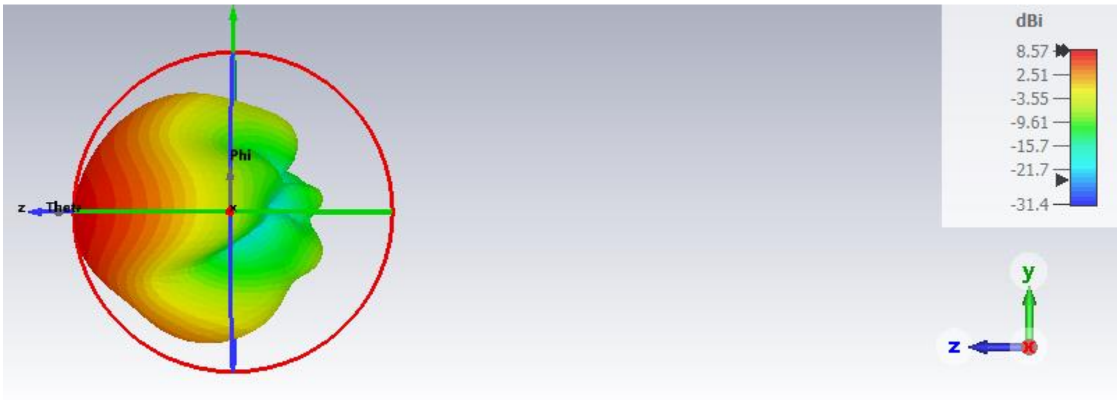

Figure 11. 3D Radiation Pattern Graphic

6-4- VSWR

A transmission line has a reflection coefficient that indicates the percentage of the wave that is reflected when an impedance break occurs along the line. The following equation describes the reflection coefficient when it is written in terms of the load impedance Z_L and the line impedance Z_o.

$$S_{11} = \frac{Z_L - Z_O}{Z_L + Z_O} \tag{6}$$

The voltage standing wave ratio, or VSWR, is the proportion of the minimum and maximum voltage that a standing wave has while it is travelling through the transmission line. It reveals the quantity of power that has been drained from the origin. It has a tight relationship with the reflection coefficient, as seen by the Equation 7.

$$VSWR = \frac{1+\sqrt{S_{11}}}{1-\sqrt{S_{11}}} \tag{7}$$

As can be seen from Equations 6 and 7, the minimal value for VSWR is reached when S11 is reduced to its lowest possible value. To prevent an excessive amount of reflection, the design process must guarantee that the VSWR is as low as possible.

The value of 2.3 was found to be the VSWR when measured at 30 GHz, as shown in Figure 12. This value of the voltage standing wave ratio (VSWR) falls within the permitted range since patch antennas have a low efficiency in terms of the amount of power they use. The transition from one part of the bandwidth to another is quite smooth, and the VSWR progressively becomes higher as it gets closer to the lower frequencies.

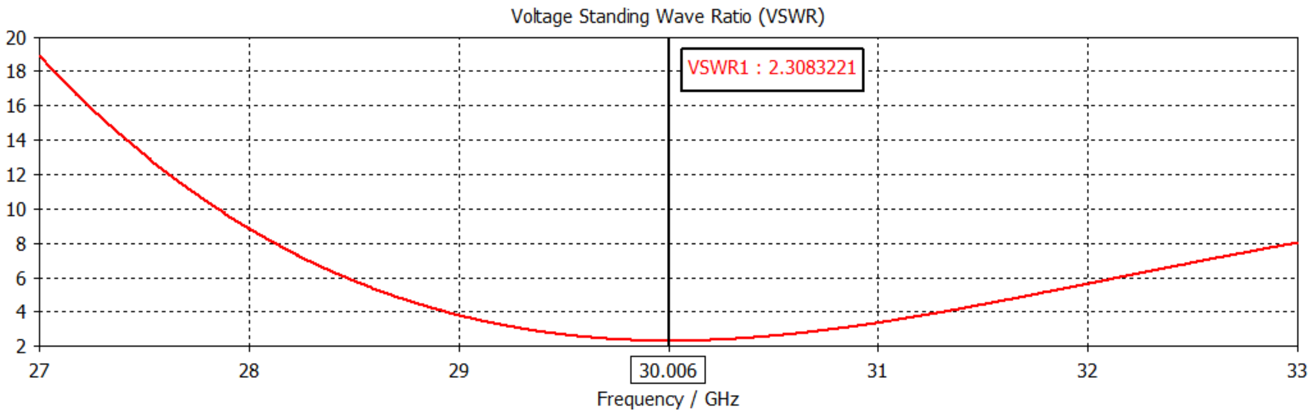

Figure 12. VSWR Performance vs. Frequency

6-5- Results Comparison

The performance of the proposed patch antenna is compared in Table 3 to the performance of several alternative designs that operate at the same frequency. The proposed antenna has a wide bandwidth, a high gain, and equivalent directivity and reflection coefficients. These characteristics make the proposed antenna an attractive option.

Table 3. Result Comparison

Parameter	Present Study	Kiran et al. (2018) [11]	Sharaf et al. (2020) [34]
Resonant Frequency (*GHz*)	30	28.3	28
Bandwidth (*GHz*)	3.5 (28.5 to 32)	2.2 (27.8 to 30)	2.68
Gain	8.45	2.6	5.06
S11 (*dB*)	-8	-11	-12.5
Directivity (*degrees*)	5	6	N/A
VSWR	2.3	1.58	1.162

As can be observed from Table 3, the design that has been presented has a greater bandwidth and also gains at a frequency range that is around 30 GHz. The use of the C slot and the utilization of dipole fields in addition to the normal patch field contributed to the improved bandwidth value of 3.5 GHz that was achieved. By eliminating the impedance mismatch and making up for the higher VSWR of 2.3, the inclusion of the quarter wave feed enables the antenna to exhibit a high gain of 8.45. When looking at other designs, it can be noted that although they have a reduced VSWR, the gain is not exhibiting comparably efficient values due to an impedance mismatch that is present in the designs. This is apparent when comparing these designs to others. As can be seen by looking at the graphs, the design that has been suggested also has a superior beamwidth and directivity. This is as a result of the incorporation of a slot in the form of a C and the use of a dielectric constant that is lower inside the substrate.

7- Conclusion

As 5G grows more widespread in markets all around the globe, a greater number of devices are connecting to 5G networks, which in turn increases the need for antennas that are both effective and efficient. The Internet of Things (IoT) market is expanding at a fast rate, which is further boosting the need for antennas that are capable of functioning in the mmWave frequency band yet have compact dimensions. Patch antennas are preferred by all these market trends because they provide excellent performance over the necessary range and are affordable to manufacture. In addition, their compact size makes it simple to incorporate them into the existing technology without the need to make significant alterations to the designs that were already in place. The incorporation of slots into patch antennas has been the subject of study since the early 1980s. This modification to the conventional design of patch antennas results in significant enhancements to the antenna's directivity combined with beamwidth. These enhancements are perfect for the applications that patch antenna are now used for. For instance, the antenna that is used for Internet of Things devices has to be able to connect to a huge number of devices over a wide region. These slotted patch antenna designs may be used in lieu of traditional antennas at a far lower cost and with very few modifications to the design itself.

The suggested antenna was successful in attaining the following results: a gain of 8.45 dB at 30 GHz, a reflection of -8 dB, and a VSWR of 2.3. These values are in line with the norms that are generally accepted in the industry. The dimensions of the design are 3.462 by 2.602 millimeters. In addition, the suggested design exhibits excellent beamwidth in addition to directivity at an angle of 5 degrees. There is reason to believe that it might be useful in midband wave mobile applications because of its diminutive size, straightforward production, and easy incorporation processes.

7-1- Future Work

The use of slots or slot loading results in improved resonant frequency adaptability, greater gains, and improved directivity. The creation of dipole antennas and complementary dipole antennas in accordance with Babinet's approach [35] is responsible for these much-enhanced outcomes. Therefore, an additional slot in the form of a C might be added to further improve these advantages.

8- Declarations

8-1- Author Contributions

Conceptualization, A.R.; methodology, A.R., and S.K.; software, A.R., and S.K.; validation, A.R., and S.K.; formal analysis, A.R., and S.K.; investigation, A.R., and S.K.; resources, A.R., and S.K.; data curation, A.R., and S.K.; writing—original draft preparation, A.R., and S.K.; writing—review and editing, A.R., and S.K.; visualization, A.R., and S.K.; supervision, A.R.; project administration, A.R.; funding acquisition, A.R. All authors have read and agreed to the published version of the manuscript.

8-2- Data Availability Statement

Data sharing is not applicable to this article.

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8-5- Institutional Review Board Statement

Not applicable.

8-6- Informed Consent Statement

Not applicable.

8-7- Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

9- References

[1] Miao, G., Zander, J., Sung, K. W., & Slimane, S. Ben. (2016). Fundamentals of mobile data networks. Cambridge University Press, Canbridge, United Kingdom. doi:10.1017/CBO9781316534298.

[2] Rajesh, V., Kompella, S.K., Abdul Rajak, A.R. (2022). Literature Survey for MIMO Systems and Interference Cancellation in MIMO. ICT Systems and Sustainability. Lecture Notes in Networks and Systems, 321, Springer, Singapore. doi:10.1007/978-981-16-5987-4_1.

[3] Johnson, D. (2020). 4G Vs. 5G: Key Differences Between the Network Generations. Insider. Available online: https://www.businessinsider.com/4g-vs-5g (accessed on July 2022).

[4] QualcoMM. (2022). What is 5G | Everything You Need to Know about 5G | 5G FAQ. QualcoMM, San Diego, United States. Available online: https://www.qualcomm.com/5g/what-is-5g (accessed on June 2022).

[5] Samsung. (2018). Who & How: Making 5G NR Standards. Samsung, Suwon-Si, South Korea. Available online: https://images.samsung.com/is/content/samsung/p5/global/business/networks/insights/white-paper/who-and-how_making-5g-nr-standards/who-and-how_making-5g-nr-standards.pdf (accessed on April 2022).

[6] Howell, J. (1972). Microstrip antennas. Antennas and Propagation Society International Symposium, Williamsburg, USA, IEEE. doi:10.1109/aps.1972.1146932.

[7] Kompella, S.K., Abdul Rajak, A.R. (2022). Design and Study the Performance of Micro-Strip Patch Antennae for 5G Mobile Communication. ICT Systems and Sustainability. Lecture Notes in Networks and Systems, 321. Springer, Singapore. doi:10.1007/978-981-16-5987-4_2.

[8] Denlinger, E. J. (1969). Radiation from Microstrip Resonators. IEEE Transactions on Microwave Theory and Techniques, 17(4), 235–236. doi:10.1109/TMTT.1969.1126937.

[9] Tutorialspoint. (2022). Antenna Theory - Micro Strip. Tutorialspoint Simply Easy Learning, Hyderabad, India. Available online: https://www.tutorialspoint.com/antenna_theory/antenna_theory_micro_strip.htm (accessed on July 2022).

[10] Sekhararao, K. C., & Babu, C. (2016). Design of C-shape slot microstrip patch antenna with line feed for WLAN technology. Journal of Electronics and Communication Engineering (IOSR-JECE), 11(6), 72–78. doi:10.9790/2834-1106047278.

[11] Kiran, T., Mounisha, N., Mythily, C., Akhil, D., & Kumar, T. P. (2018). Design of microstrip patch antenna for 5G applications. Journal of Electronics and Communication Engineering (IOSR-JECE), 13, 14-17. doi:10.9790/2834-1301011417.

[12] Engg, M. T. E. (2019). Compact Micro Strip Antenna for 5G Mobile Phone Applications. International Journal of Applied Engineering Research, 14(2), 108–111.

[13] Ramli, N., Noor, S. K., Khalifa, T., & Abd Rahman, N. H. (2020). Design and performance analysis of different dielectric substrate based microstrip patch antenna for 5G applications. International Journal of Advanced Computer Science and Applications, 11(8), 77–83. doi:10.14569/IJACSA.2020.0110811.

[14] Yon, H., Abd Rahman, N. H., Aris, M. A., & Jumaat, H. (2020). Developed high gain microstrip antenna like microphone structure for 5G application. International Journal of Electrical and Computer Engineering, 10(3), 3086–3094. doi:10.11591/ijece.v10i3.pp3086-3094.

[15] Ul, Z., & Ullah, Z. (2017). Design of a Microstrip Patch Antenna with High Bandwidth and High Gain for UWB and Different Wireless Applications. International Journal of Advanced Computer Science and Applications, 8(10), 379–382. doi:10.14569/ijacsa.2017.081049.

[16] Al Kharusi, K. W. S., Ramli, N., Khan, S., Ali, M. T., & Halim, M. A. (2020). Gain enhancement of rectangular microstrip patch antenna using air gap at 2.4 GHz. International Journal of Nanoelectronics and Materials, 13, 211-224.

[17] Kumar, R., Shinde, J. P., & Uplane, M. D. (2009). Effect of slots in ground plane and patch on microstrip antenna performance. International journal of recent trends in engineering, 2(6), 34.

[18] Bhunia, S. (2012). Effects of slot loading on microstrip patch antennas. International journal of wired and wireless communications, 1(1), 1-6.

[19] Ojaroudiparchin, N., Shen, M., & Pedersen, G. F. (2015, November). A 28 GHz FR-4 compatible phased array antenna for 5G mobile phone applications. In 2015 International symposium on Antennas and propagation (ISAP), 9-12 November, 2015, Hobart, Australia.

[20] Palanivel Rajan, S., & Vivek, C. (2019). Analysis and design of microstrip patch antenna for radar communication. Journal of Electrical Engineering and Technology, 14(2), 923–929. doi:10.1007/s42835-018-00072-y.

[21] Wang, Z., Liu, J., & Long, Y. (2019). A Simple Wide-Bandwidth and High-Gain Microstrip Patch Antenna with Both Sides Shorted. IEEE Antennas and Wireless Propagation Letters, 18(6), 1144–1148. doi:10.1109/LAWP.2019.2911045.

[22] Islam, M. S., Islam, M. T., Ullah, M. A., Beng, G. K., Amin, N., & Misran, N. (2019). A Modified Meander Line Microstrip Patch Antenna with Enhanced Bandwidth for 2.4 GHz ISM-Band Internet of Things (IoT) Applications. IEEE Access, 7, 127850–127861. doi:10.1109/ACCESS.2019.2940049.

[23] Colaco, J., & Lohani, R. (2020). Design and Implementation of Microstrip Circular Patch Antenna for 5G Applications. 2020 International Conference on Electrical, Communication, and Computer Engineering. doi:10.1109/icecce49384.2020.9179263.

[24] Punith, S., Praveenkumar, S. K., Jugale, A. A., & Ahmed, M. R. (2020). A Novel Multiband Microstrip Patch Antenna for 5G Communications. Procedia Computer Science, 171, 2080–2086. doi:10.1016/j.procs.2020.04.224.

[25] Sankar Ponnapalli, V. A., Reddy, K. D., & Aqeel, S. (2020). Parametric Study and Analysis of Microstrip Patch Antenna with Multiple Slit Positions. Carpathian Journal of Electronic and Computer Engineering, 13(1), 1–4. doi:10.2478/cjece-2020-0001.

[26] Darboe, O., Konditi, D. B. O., & Manene, F. (2019). A 28 GHz Rectangular Microstrip Patch Antenna for 5G Applications. International Journal of Engineering Research and Technology, 12(6), 854–857.

[27] Lodro, Z., Shah, N., Mahar, E., Tirmizi, S. B., & Lodro, M. (2019). mmWave Novel Multiband Microstrip Patch Antenna Design for 5G Communication. 2019 2nd International Conference on Computing, Mathematics and Engineering Technologies (iCoMET). doi:10.1109/icomet.2019.8673447.

[28] Kim, G., & Kim, S. (2021). Design and Analysis of Dual Polarized Broadband Microstrip Patch Antenna for 5G mmWave Antenna Module on FR4 Substrate. IEEE Access, 9, 64306–64316. doi:10.1109/ACCESS.2021.3075495.

[29] Islam, R., Mahbub, F., Abdul Kadir Al-Nahiun, S., Banerjee Akash, S., Rashidul Hasan, R., Abdur Rahman, M. (2022). Design of an On-Body Rectangular Microstrip Patch Antenna for the Diagnosis of Breast Cancer Using S-Band. Proceedings of Sixth International Congress on Information and Communication Technology, Lecture Notes in Networks and Systems, 216, Springer, Singapore. doi:10.1007/978-981-16-1781-2_89.

[30] Garg, R., Bhartia, P., Bahl, I. J., & Ittipiboon, A. (2001). Microstrip antenna design handbook. Artech House, Massachusetts, United States.

[31] Johnson, H., Johnson, H. W., & Graham, M. (2003). High-speed signal propagation: advanced black magic. Prentice Hall Professional, Hoboken, United States.

[32] Shi, L., Yan, M., Li, J., & Zhao, Y. (2022). The Integrated Design of Millimeter Wave Insert Fed Circular Microstrip Patch Antenna and Radome. 2022 4th International Conference on Communications, Information System and Computer Engineering (CISCE). doi:10.1109/cisce55963.2022.9851067.

[33] Rogers Corporation (2022). RT/duroid® 5870 /5880 Data Sheet-High Frequency Laminates. Rogers Corporation, Arizona, United States. Available online: https://rogerscorp.com/-/media/project/rogerscorp/documents/advanced-electronics-solutions/english/data-sheets/rt-duroid-5870---5880-data-sheet.pdf (accessed on June 2022).

[34] Sharaf, M. H., Zaki, A. I., Hamad, R. K., & Oma, M. M. M. (2020). A novel dual-band (38/60 GHz) patch antenna for 5g mobile handsets. Sensors (Switzerland), 20(9), 2541. doi:10.3390/s20092541.

[35] Electronics Desk (2022). What is Slot Antenna? Working and Applications of Slot Antenna. Electronics Desk. Available online: https://electronicsdesk.com/slot-antenna.html (accessed on June 2022).