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Design and Study of the Performance of Patch Antenna with Double C Slot for MIMO-OFDM Based Communications Systems for Media Technology

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Abstract – *Mobile phones, server stacks, and other high-bitrate devices demand greater bandwidth from antennas. More bandwidth means higher bitrates and more data sent. MIMO antennas simultaneously deliver and receive data. MIMO antennas can broadcast data to unreachable places with little noise. Multiple data streams and multipath propagation boost performance and data quality. Many antennas allow MIMO systems to send and receive data at regular intervals. These antennas can perform beamforming and determine a signal's 3-D route. OFDM increases bitrates at the same frequency by multiplexing without guard bands. Multiple orthogonal carrier frequencies increase data in the same bandwidth and avoid carrier distortion. Air gaps, parasitic patches, and substrate modifications are methods to increase bandwidth and beam width for patch antennas. The conventional patch pattern has been modified and refined for maximum success. This article proposes a patch antenna with double C slots. This new design features a large bandwidth, wide beamwidth, and multidirectional transmission pattern. The gain, VSWR, and reflection coefficient of this patch antenna meets the MIMO-OFDM systems with 5G standard. Hence the proposed antenna design is recommended to employ in the MIMO-OFDM system for 5G applications.*

Keywords: *MIMO, OFDM, VSWR, C-Slot, Patch Antenna*

Nomenclature

3G, 4G, 5G	Third, fourth, fifth generation
FDM	Frequency Division Multiplexing
FR-2	Frequency Range 2
IoT	Internet of Things
LDACS	L-Band Digital Aeronautical Communication System
LTE	Long Term Evolution
MIMO	Multiple In Multiple Out
OFDM	Orthogonal Frequency Division Multiplexing
SISO	Single In Single Out
VSWR	Voltage Standing Wave Ratio
ε	Dielectric constant
f	Frequency
h	Height
φ	Horizonal plane angle
Z	Impedance
S_{11}	Reflection coefficient
c	Speed of light
t	Thickness
θ	Vertical plane angle
λ_o	Wavelength
W	Width

I. Introduction

Throughout the years, technological advancements in communications have progressed from enormous antennas to more compact devices such as cell phones.

The last two decades have concentrated on increasing network speed and efficiency while emphasizing dependability. Such an increase in speed and efficiency is made possible by using a communications network. This network is composed of cell towers covering a cell site and transferring signals to satellites or larger cell towers.

This action is repeated on the receiving end as well to finish establishing the connection activity. The latency and data rate of the communication between the devices and the towers are what the standards take into consideration.

Earlier technologies such as LTE and 3G did not posses extremely high-performance qualities when compared to more recent ones. The recent trend within the industry is the 5G standard, which boasts a very low latency of 1 millisecond and extremely high data rates of 50 Mbps [1].

The frequencies utilized for these standards are selected because of several considerations, including availability, practicability, and technical requirements.

As can be seen in Fig. 1, the 5G standard includes two distinct frequency bands reserved for use.

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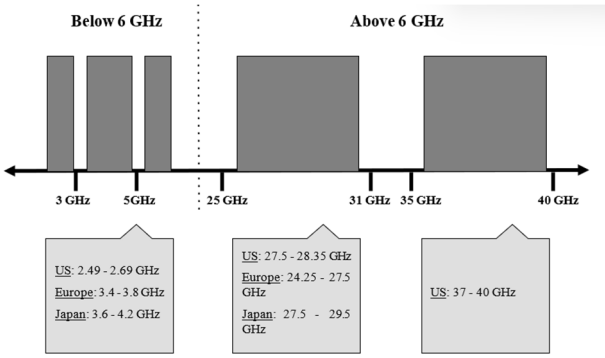

Fig. 1. Overview of 5G Frequency Band

The mmWave spectrum, often known as waves with wavelengths in the millimeter range, is used within the FR-2 frequency range. Because of the way in which patch antennas emit their signals, this frequency range is well suited for its use. Patch antennas achieve their highest level of efficiency when used at mmWave ranges. However, a single patch antenna cannot achieve the desired coverage and bitrate for all the devices within the area. Different types of antenna configurations have been implemented over the years. The current trend is Multiple-In Multiple-Out (MIMO) communication system, which contain multiple antennas that can simultaneously broadcast or receive information. MIMO can also employ Orthogonal Frequency Division Multiplexing (OFDM). OFDM utilizes a method of multiplexing to achieve higher bitrates within the same frequency band. Regular multiplexing involves a separation, called a guard band, between different carriers.

This ensures that different data streams do not mingle and distort data at the receiving end. However, the need for guard bands means that the bandwidth is being used for data along with non-data guard bands. On the other hand, with the OFDM technique, the bandwidth does not contain these guard bands. Instead, multiple carrier frequencies are orthogonally placed next to each other, allowing for a larger amount of information within the same bandwidth. Distortion is avoided through careful selection of the carriers. Assuming the n number of carrier frequencies, at the maxima of any one carrier, the n-1 carriers will have a minima. This ensures that the receiver can easily decode the information.

The difference between simple FDM and OFDM is portrayed in Fig. 2 [2]. These MIMO systems contain many antennas placed in key orientations such as 2×2, 4×4, 8×8, and so on, depending on the requirement. Fig. 3 shows a MIMO design with a 5×5 antenna configuration. All the antennas in the transmission transmit to all the antennas in the receiver. This may differ in applications based on the requirement and configuration of the systems. The main feature of MIMO antennas over their predecessor Single-In Single-Out (SISO) antennas is their ability to transmit extremely large amounts of data with very low noise to inaccessible points.

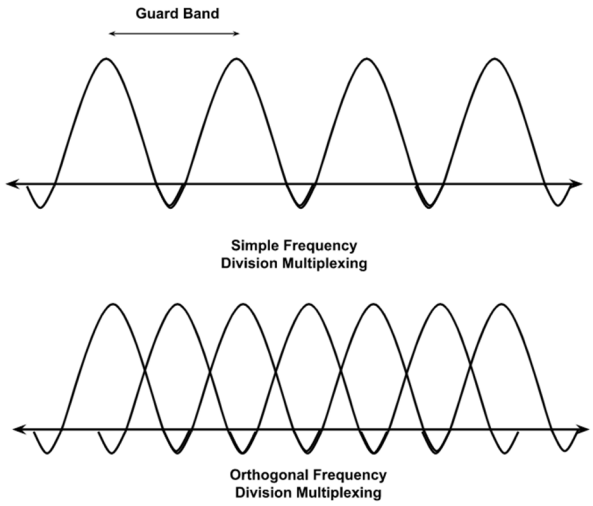

Fig. 2. Comparison of FDM and OFDM

Techniques such as multipath propagation and multiple data streams allow these systems to accomplish very high throughput and greater quality of information.

Due to the presence of multiple antennas, MIMO systems can send and receive information at stagnated time intervals. Furthermore, they can use these multiple antennas to perform spatial filtering, commonly referred to as beamforming. This involves using multiple antennas to choose the 3-dimensional path that the signal will take. This is achieved through careful constructive and destructive interference from all the participating antennas. This allows the transmitter to move around obstacles and reach points that are not in their line of sight [3].

As stated before, MIMO systems have many applications and benefits. The link between MIMO technology and communications systems has been greatly studied in papers such as [4] and [5].

Recommendations include different multiplexing techniques such as Turbo, Geometric Mean Decomposition, and differential Spatial Division Multiplexing. These techniques when combined with massive MIMO systems, allow the utilization of patch antennas at the mmWave range to the full of their abilities. Over time, the performance of every electrical equipment is fine-tuned to provide more impressive outcomes. The rise of high-bitrate devices like mobile phones, server stacks, and other such items has raised the need for bigger bandwidth utilization, increasing the requirement for various antennas.

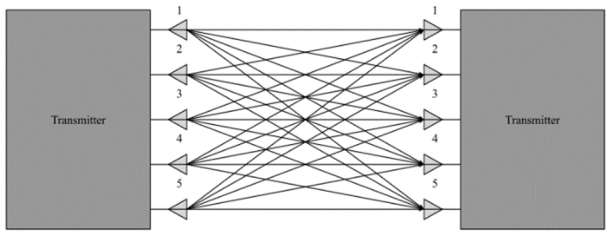

Fig. 3. Example of MIMO System

Greater bandwidths would make it possible to accommodate greater bitrates, resulting in the transmission of even more data than was previously possible. A significant disadvantage of microstrip antennas is that they only have a restricted bandwidth, which is becoming more noticeable than ever before. The current bandwidth values, on the other hand, range from 15% for antennas with dipoles to 90% for antennas with several bandwidth augmentation methods [6]. These changes are due to a large amount of research that has been conducted on this issue. Among these research methods are the installation of air gaps and parasitic patches, as well as the modification of certain substrate properties. This paper presents a novel double C slotted microstrip fed patch antenna built on Rogers RT druid 5880 substrate. The theory associated with a patch antenna and the relationship between antenna performance and substrate selection is briefly looked at in section two. A literature review of work done in the fields of microstrip antennas, Multiple In Multiple Out (MIMO), and different applications of 5G based communications was done in section three. The design procedure employed along with the specifications and limiting factors were stated in. Finally, results such as VSWR, S_{11}, and so on were analyzed in depth.

II. Theory of Patch Antenna

II.1. Patch Antenna

Patch antennas are used frequently in tiny devices, like Internet of Things (IoT), that need radio communication. These situations demand inexpensive, minimum, and effective radio communication. The fundamental design of a patch antenna is similar to that of a capacitor in that it consists of two metal plates, one of which is the ground, and the other is the patch, and a substrate material that is sandwiched in between these two metal plates.

The basic structure is displayed in Fig. 4. All patches also require a feeding mechanism for excitation. Some examples of feeding mechanisms are strip feeds, probe feeds, aperture feeds, and so on. Every element that makes up the construction of the patch antenna must have its fine tuning adjusted so that it satisfies the specifications and demands. Because this is the section of the patch that resonates with the operating frequency, the size and form of the patch are both highly essential considerations. The necessity may call for the use of a variety of forms, including triangular, rectangular, or round, amongst others. In addition, enhancements such as stubs, slots, or probes may be added to increase gain and directivity. However, this will result in a decrease in power output. The selection of the substrate is also highly significant since each substrate has its unique set of electrical characteristics, and the substrate must be selected according to the requirements. The operation is more complicated than that of a capacitor because the patch antenna must radiate in a particular direction while also achieving an adequate level of power and gain.

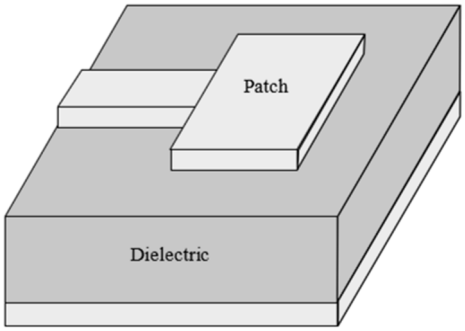

Fig. 4. Structure of a Patch Antenna

If the antenna is constructed correctly, a standing wave should be able to develop at the surface of the patch. This would make it possible for a voltage differential to build up through the substrate in relation to the ground. The standing wave is produced because of the open-ended transmission line arrangement that the patch has. Because of this, a patch antenna behaves more like a voltage radiator than a current radiator. As a result, optimizing characteristics such as VSWR and reflection coefficient becomes very critical. Because the standing wave can only be produced at the working frequency, the physical size of the patch has a direct bearing on how well it performs and how efficiently it operates within a certain frequency range. The fields that are contained inside the substrate provide a contribution to the fringing fields that are located around the lengthwise margins of the patch. These fields not only contribute to the radiation being set in the positive Z direction, which enables the patch to operate as an antenna, but they also help increase the effective radiating length of the patch, which is an additional benefit [7].

II.2. Substrate and Air Gap of Patch

The substrate is a very important component of a patch antenna. It provides the medium through which the antenna can radiate and therefore is a very crucial component to fine tune. The substrate provides the region within which the voltage difference between the patch and ground can exist, leading to the formation of radiation, as depicted in Fig. 5. Height and dielectric constant are the two primary factors that may be altered for the substrate. Their implications have been explained in studies as mentioned in [8]. The constraint imposed by the wavelength that is being used is the primary factor that decides the height of the substrate. The optimum zone is shown in s no. 1 and increasing the substrate height results in wider bandwidths owing to a wider spread of the fringing fields. However, when the height approaches its upper limits, the substrate starts to excite higher modes of the frequency, which results in dampening of radiation and lower results. In Equation (1) λ_o represents the frequency being used and h represents the heigh of the substrate:

$$0.003\lambda_o \leq h \leq 0.05\lambda_0 \quad (1)$$

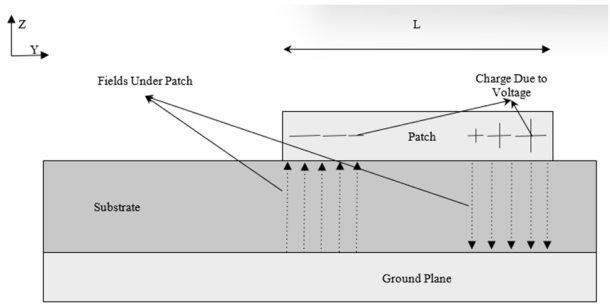

Fig. 5. Function of Substrate in a Patch Antenna

Altering the substrate itself will result in a different value for the dielectric constant. There is a wide variety of substrates to choose from, each of which has a unique set of characteristics, including thermal conductivity, uniformity across frequencies, cost, simplicity of production, and so on. Reducing the value of the dielectric constant leads to changes that are analogous to those brought on by raising the height; however, there are additional constraints that must be considered. There is a possibility that the design is very temperature sensitive, or that there are financial constraints, both of which restrict the use of a substrate that has a low dielectric constant. Therefore, altering the substrate is not always the best option to reduce the value of the dielectric constant, and the inclusion of an air gap is a good alternative that is also very inexpensive to do. According to the results of Equation (2), where h_1 and h_2 are the heights of the substrates and 'ε_r' is the substrate dielectric constant. As a result, the dielectric constant is decreased because of the insertion of the air gap, which allows for improved gain as well as bandwidth [6]:

$$\varepsilon_{resultant} = \frac{(h_1 + h_2)\varepsilon_r}{(h_1 + h_2\varepsilon_r)} \tag{2}$$

A gap of air is injected between the substrate and the ground to create what is known as an air gap, which is seen in Fig. 6. This functions as an extension of the substrate and alters some of the functions given by a substrate, namely the height and the electric permeability. This makes it possible to increase bandwidth by fine-tuning the air gap height. The diversity of substrates available is restricted for several different reasons, including price and the electrical characteristics of each material. However, the height of the substrate-air combination may be adjusted, as well as its permeability, if an air gap is included in the design.

The insertion of an airgap is done in response to specific needs. The bandwidth undergoes a dramatic transformation when an air gap is introduced, as seen by the fact that it significantly expands after this shift, as illustrated in [30]. In addition, the theory that underpins the incorporation of an air gap is consistent over a wide range of patch designs and sizes owing to the straightforward capacitor setup that is characteristic of patch antennas.

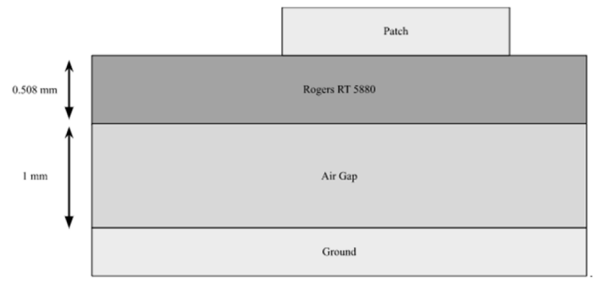

Fig. 6. Introduction of an Air Gap

As a result, the creation of an air gap is a simple process. An air gap's principal purpose is to reduce the electrical permeability of an antenna while preserving the flexibility to adjust the height of the substrate. This is accomplished while the air gap remains in place. Because of this air gap, a change in capacitance is observed, which will affect the calculations of the patch antenna design parameters. Air gap size gets adjusted to obtain maximum gain and directivity in the bandwidth of operation.

III. Literature Survey

Broadband antennas have been more popular in recent years, as R. Mishra [8] et al. have pointed out, along with the many applications for which they might be used.

They then went on to describe the characteristics that determine the widening of antenna bandwidth as well as the way the effects of those parameters are explored in their research. L. C. Paul [9] et al. discussed the significance of substrates in relation to the operation of patch antennas in their research. They detailed not only the research methods that they used to get an understanding of the working of the selected substrates, but also the particulars of their configuration. M. I. Khattak [10] and colleagues provided a comprehensive discussion on the findings they had collected about the primary elliptical slot antenna. In addition to this, they elaborated the dimensions and outcomes of the array system that was used, as well as the simulation software that was applied. J. J. Borchardt [11] et al. provided an explanation of the approach that was used while analyzing the U-shaped slot, as well as the many modes of frequencies that were investigated. They described the circuit layouts that they used for the research as well as the redundancies that were discovered in their designs.

W. A. Awan [12] and colleagues provided an in-depth discussion on the design standards for the European Standard Telecommunications as well as the alterations that were made to their plan to allow for these requirements. They provided a rundown of the design's operational characteristics, as well as the modelling software that was being used. T. H. Jang [13] and colleagues showed the dimensions of their device as well as its operational parameters. They provided a comprehensive explanation of the modifications, which included a slot, a port, and a feed. In addition to that, they

provided a list of potential applications for their concept. R. K. Verma [14] et al. brought attention to the form that was used in the research on the expansion of bandwidth.

They showed the outcomes that they acquired as well as the applications of the enhancing approaches that they used. A. Madankar [15] and fellow researchers listed the parameters of their design and its applications. They also mentioned the results they obtained such as VSWR, gain, and so on. O. W. Ata [16] and research associates derived the equations of their design along with the design parameters. They went on the specify the fabrication process along with the experimental results obtained. H. Wu [17] et al. described the type of patch antenna designed along with the modes they were exciting. They detailed the outcomes they had achieved in addition to the specifications of the design. P. Liu [18] and colleagues provided a comprehensive breakdown of the structure, size, and components that were included into their overall design. Additionally, they detailed the outcomes that they attained both via the simulations that they ran and the practical implementation of their concept. M. K. Ray [19] and colleagues depicted the operation of their construction as well as the spacing and orientation of the slots that they included into their system. They also provided the data that they acquired, including bandwidth, radiation characteristics, and gain, among other things. E. Li [20] et al. emphasized the advancements that have been made in communications as well as the positive aspects of their design. They then proceeded to describe the many uses for their design. B. Aghoutane [21] and colleagues provided specifics on the structure and composition of their design, in addition to providing measurements for both the antenna and the substrate. They discussed the simulation software that was utilized as well as the findings that were produced from the simulations. K. Xiang [22] and colleagues brought attention to the material that was presented in their work, which covered the kind of design, revisions, and the design process. They detailed the outcomes that were achieved in addition to the enhancements made to their design. M. M. H. Mahfuz [23] et al. highlighted the benefits and drawbacks of current advancements in antenna technology. They discussed the specifics of their form in great depth, including the applications of their design as well as the methodologies that were utilized to justify its usage. B. Saikia [24] and colleagues provided a comprehensive description of the structure, components, and adjustments made to their layout. They discussed the frequency of their operations, as well as the simulation software that was used and the findings that were achieved. M. Keshkar [25] et al. illustrated the importance of clear and interference free information processing within the aeronautical communication sphere. They further specified the method of analyses used for their design along with the improvements they performed based on the results they obtained. R. Muthalagu [26] et al. went into detail about their design specification and applications. They also specified the method of analysis and the results they obtained through simulation software, whose parameters were listed as well. S. Kompella [27] and colleagues categorized the merits and demerits of MIMO antenna systems. They also mentioned the parameters and performance of the designs and studies that were looked at within their paper. V. Rajesh [28] et al. described the formation of cochannel interference and how the MIMO antenna system is utilized for studying cochannel interference.

They specified the different performance enhancement techniques used along with the method of employing these techniques. L. Mathew [29] and researchers spoke about the promise of LDACS technology, and the modifications made to their design to meet the need of reducing interference. They highlighted the simulation software used along with the modeling methods used and the results obtained. From this literature survey, there is a gap which demands the design of an appropriate antenna for MIMO OFDM system using the 5G standard.

IV. Problem Statement, Aim and Scope

The lack of horizontal and vertical directivity that is typical of traditional patch antenna designs has become prevalent in today's communication landscape.

Furthermore, conventional patch antennas cannot be easily employed within MIMO systems to achieve OFDM without relevant adjustments being made. The literature review showed that there are very few slotted antennas that can utilize the dipole fields of the slots to their full potential. In the FR2 band, there is also a need for antennas that are omnidirectional. The absence of relevant literature and designs in these fields is addressed by design shown in this study with a double C-slotted microstrip fed patch antenna.

V. Design of Proposed Double C Slot Patch Antenna

V.1. Theory For Slots and Dipoles

A standard antenna may be converted into a slot antenna by cutting a section out of the surface which has tendency of radiation. H. G. Booker was the first person to explain this kind of antenna in 1946. In his explanation, he made a reference to Babinet's Principle, which is a concept in optics [30]. Babinet's Principle describes the connection that exists between a structure that is opaque and a cavity that has the same dimensions.

In terms of optics, the intensity of the diffraction pattern created by any one of these entities would be the same.

This was then transferred to antennas, and it was found that a radiating patch with a slot would have the same radiation pattern as an antenna that had the same size as the slot. The two structures that can be seen in Fig. 7 are referred to as dual antennas, and they are complementary to one another because of the interaction from Babinet [31]. One of the structures has the slot, while the other structure is in the form of the slot.

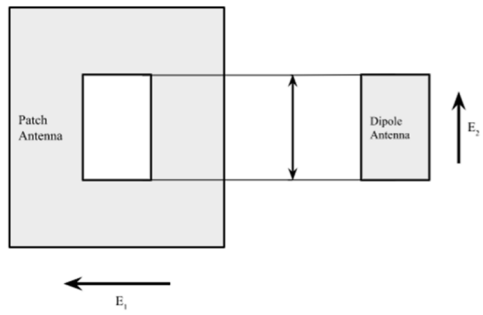

Fig. 7. Dual Antennas

Because of the one-to-one correlation that exists between a dipole antenna and a slotted patch antenna, the operational characteristics of a dipole antenna may be included in the functional parameters of a patch antenna.

The radiation characteristics and bandwidth are considered in this process. The radiation characteristics exhibits that antenna is omnidirectional or not. The beamwidth and bandwidth of the farfield radiation characteristics may be adjusted by creating slots inside the patch. This allows for a greater degree of control.

However, the size of the antenna will need to be fine-tuned to achieve optimum performance as mentioned in [32]. As can be seen in Fig. 8, a voltage difference exists between the two edges of the radiating metal surface, which allows for slots inside the surface to also radiate.

The patch antenna emits radiation because its physical structure resonates at a frequency that is in tune with the frequency of the wave that is being sent, as was discussed before. In a similar manner, the slot radiates because of the physical structure being about half of a wavelength long, with the width being much smaller.

The longitudinal margins of this construction are designed to accommodate a transmission line with an open circuit. The working of the open circuit is like that of a patch antenna. This open circuit enables the generation of a voltage difference between the top and bottom edges. This voltage difference will result in the production of a dipole radiating element, and this formation will be determined by the frequency of the current that is being employed. Therefore, similar to the design of a patch antenna, the dimensions of the slot need to be optimized so that it is possible for the voltage difference to build up and form an electric field. This electric field must be complementary to the field that is being produced by the patch. If the patch fields and the slot fields are not complementary to one another, the slot fields will diminish the total antenna field, which is something that should be avoided. In accordance with Babinet's concept, the field that is generated by the slot is like that which is generated by a dipole antenna, except for the orientation, mainly that the field of a slot is perpendicular to the structure of the slot, while the field of a dipole is parallel to the dipole structure. This phenomenon is because the slot has open circuit ends on both sides; hence, the slot is also a voltage radiator [33].

When combined with lower dielectric substrates, the incorporation of slots has been proven to result in a gain in bandwidth, radiation efficiency, and directivity, as can be seen in [32] and [33]. As was said before, this is because the patch and slot fields are adding up to the total. This enhancement will only take place if the dimensions of the slot are precisely adjusted to correspond with the frequency that is being used in conjunction with the patch. Furthermore, the addition of extra slots will need more tuning to get the fields that complement each other. However, it has been shown that slots cause a decrease in the resonance frequency of the antenna, in addition to requiring more power. It is possible to lessen the impact that these parameters have by using substrates with a lower dielectric constant and by tailoring the feed point to match the impedance.

V.2. Design Procedure of Proposed Patch Antenna

During the design process, the different changes made to the standard patch design were optimized. When choosing changes like the air gap, slots, and feed, it is important to keep an eye on things like VSWR, gain, and directivity. Fig. 9 is a flowchart of the design process used to get the final design's ideal operating frequency and dimensions. Each cycle, the air gap height, the size of the c slot, and the operating frequency are changed.

Transmission line and cavity model analysis of patch antenna is used to figure out the formulas for the specifications.

V.3. Design Analysis of Proposed Double C Slot Antenna

The major parameters to determine are the patch width, patch length, effective dielectric constant, and the feed width. The formulae utilize values for substrate height and dielectric constant. Due to the addition of an air gap, the design values will be different when compared to the values used in the formulae. The formulae do not account for the air gap, and this is compensated for through the varying of the air gap parameters during the design process, as shown in Fig. 7.

The width of the patch is given by Equation (3), where f_o is the operating frequency, and ε_r is the dielectric constant of the substrate [6]:

$$\text{Width} = \frac{c}{2f_o\sqrt{\frac{\varepsilon_r+1}{2}}} \tag{3}$$

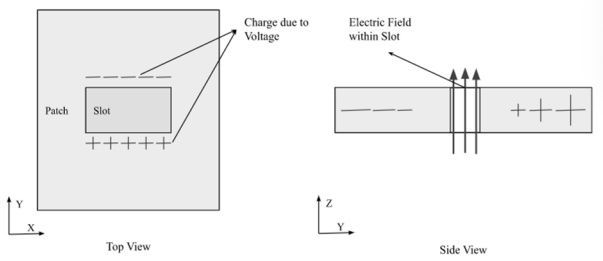

Fig. 8. Radiating Mechanism of Slots

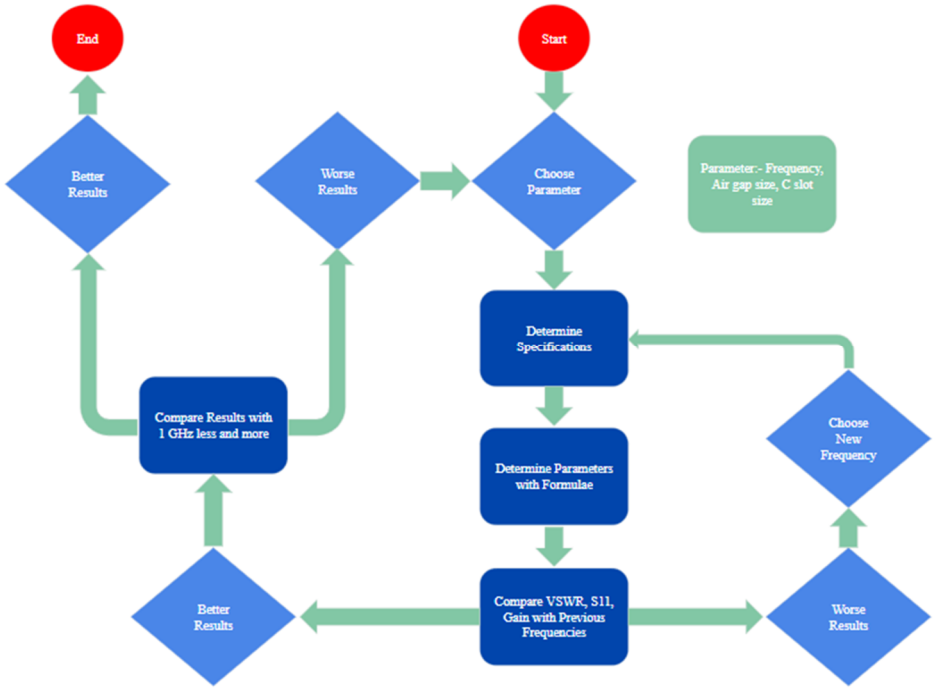

Fig. 9. Radiating Mechanism of Slots

The formula for patch length requires the effective dielectric constant which is given by ε_{eff}, expressed in Equation (4), where W is the width of the patch and h is the height of the substrate [6]:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[\frac{1}{\sqrt{1+12\left(\frac{h}{W}\right)}}\right] \tag{4}$$

The length for the patch is expressed as in Equation (5) [34]:

$$\text{Length} = \frac{c}{2f_0\sqrt{\varepsilon_{eff}}} + -\left(\frac{\left(\frac{W}{h}+0.264\right)\left(\varepsilon_{eff}+0.3\right)}{\left(\frac{W}{h}+0.8\right)\left(\varepsilon_{eff}-0.258\right)}\right)0.824h \tag{5}$$

The width of the microstrip feed is expressed in Equation (6), where Z_o is the target impedance and t is the thickness of the ground [35]:

$$W = \frac{7.48h}{\exp\left[Z_o\left(\frac{\sqrt{\varepsilon_r+1.41}}{87}\right)\right]} - 1.24t \tag{6}$$

V.4. Specifications of Proposed Design

The frequency, impedance, type of substate, the height of air gap and the metal thickness are all important design variables.

Following is a breakdown of the procedures and choices for each of these aspects:

- Skin depth is the effect wherein at higher frequencies of current, the current flow is only observed within the surface of the metals. As a result, since no current flows through the metal cavity, it may be omitted to save both material and money. As per convention, the thickness of the metal should not exceed 0.032 mm [36];
- The standard impedance for patch antennas is 50 Ω;
- The design was modeled for the FR2 band and needed to account for the drop in frequency due to the addition of slots. Through the design process mentioned above, the ideal frequency was found to be 30 GHz;
- 'Rogers RT Druid 5880' was chosen as the substrate for the design. The substrate shows high gain, low loss and consistent electromagnetic properties over a large frequency range [37]. The frequency determines the allowed lower and upper values for the substrate height as shown in Equation (1);
- The size of the air gap is set by evaluating the design repeatedly during the design process. The design needs to have a lower dielectric constant, and the size of the substrate and the air gap must be less than the height limit of the frequency. The best size for the air gap was found to be 1 mm:
- The size of the slots must be chosen so that the dipole effect allows for better radiating power while keeping the power demand from the slot moderately low. It was found that 0.4 mm was the best size.

TABLE I
SPECIFICATIONS OF PROPOSED DESIGN

Parameter	Value
Ground Thickness	0.032 mm
Impedance	50 Ω
Resonant Frequency	29.871 GHz
Dielectric Constant	2.2
Height of Substrate	0.508 mm
Height of Air Gap	1 mm
Size of C Slot	0.4 mm

V.5. Design Parameters and Structure of Proposed Double C Slot Antenna

After using the formulae specified before, the initial dimensions are calculated. The designs are then optimized by adjusting patch width, patch length, feed width and air gap height to obtain an optimal balance between the S_{11}, gain, directivity and VSWR parameters.

The functioning of the antenna is also taken into consideration while making changes to the design. Fig. 10 shows the top view of the proposed design.

VI. Results and Discussions of Proposed Design

VI.1. Performance of Reflection Coefficient

The S_{11} versus frequency graph is shown in Fig. 11.

This graph is also called the reflection coefficient graph because it shows the ratio of the power reflected by the transmission line to the total power sent by the transmission line to the load.

TABLE II
DIMENSIONS OF PROPOSED DESIGN

Parameter	Value
Patch Width	4.086 mm
Patch Length	3.153 mm
Feed Width	1.235 mm

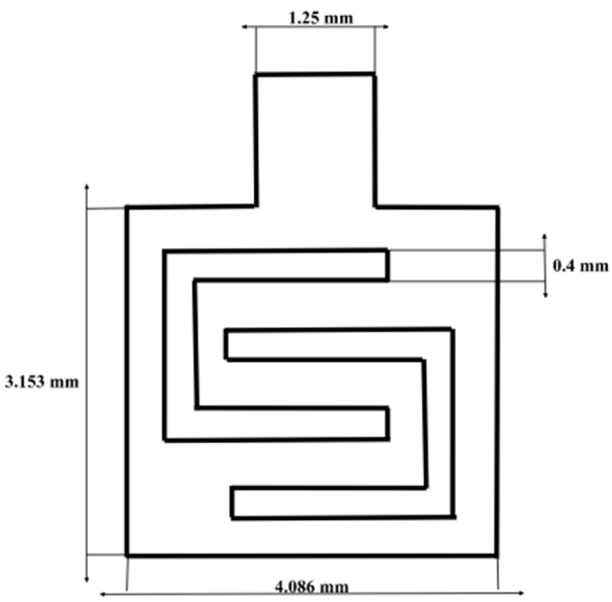

Fig. 10. Dimensions of Proposed Design

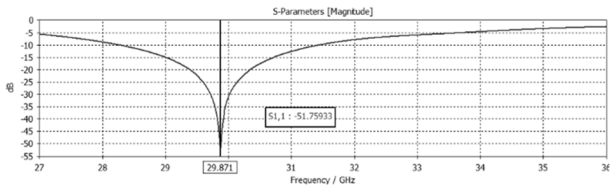

Fig. 11. Performance of Reflection Coefficient S_{11} of Proposed Antenna

This is clear from Equation (7), where Z_L is the load impedance (antenna impedance), and the line characteristic impedance is Z_O:

$$S_{11} = \frac{Z_L - Z_O}{Z_L + Z_O} \tag{7}$$

The resonant frequency of the design can also be found by finding the minima of the graph, which is the frequency at which the least power is reflected, thus having better usage of the power being supplied. This is the frequency at which the least amount of power is reflected, which means that more of the power from the source is used.

This graph also finds the bandwidth by finding the -3 dB or -10 dB cutoffs. The resonant frequency was determined to be 29.871 GHz, with a reflection coefficient of -51.75 dB. The curve displays no jumps or breaks implying that the design can function normally over a wide frequency range. The -10 dB bandwidth is found to be 3 GHz with a steady movement to the resonant frequency. The curve displays -15 dB at 29 GHz, moving to much lower values between 29 GHz and 30 GHz, with the curve mirroring around the resonant frequency.

VI.2. Performance of Gain

Fig. 12 provides a visual representation of the gain performance of the proposed double-C slot antenna. It has been determined that the gain is 8.24 at the resonant frequency.

The gain is at its highest point at 30 GHz, after which it gradually drops to 8 during 31 GHz to 34 GHz, and then it eventually reaches 7 at 36 GHz. Because the reflection coefficient and VSWR numbers could not be improved, the design had to be tweaked to work at 29.8 GHz.

The gain's distribution over the bandwidth has a maximum deviation of 0.2. As a result, the design can work effectively across the full bandwidth.

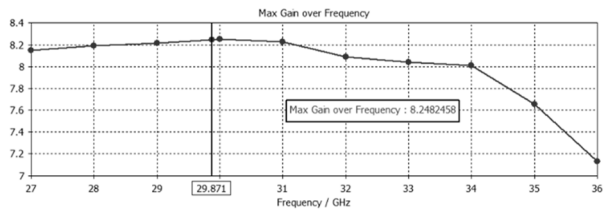

Fig. 12. Performance of Gain of Proposed Antenna

VI.3. Performance of Farfield Radiation

The farfield radiation characteristics are discussed in the following section. The term "farfield region" refers to the area in which electromagnetic radiation exhibits behavior that is consistent with electric and magnetic fields that are orthogonal to one another. Regarding antennas, this area is studied for the purpose of providing feedback on the design. The parameters such as the directivity, cross sectional radiation patterns, beam width, and many more, are analyzed through the farfield radiation results. These findings make it possible to see the influence that was caused by the inclusion of the slots, particularly in terms of the radiation patterns and beamwidths. Fig. 13 displays the polar radiation pattern of the design at the resonant frequency of 29.8 GHz. This graph reaches its highest value at an angle of 24°, with a downward trend beginning from the central angle. It has an angular width of 70.2° with low side lobes. The large angular width can be attributed to the introduction of the slots, thereby increasing the beamwidth, and ensuring maximum directivity over a large area. The top cross-sectional view of the radiation pattern is indicated by the directivity graph around θ with φ=0°, depicted in Fig. 14.

The gain in terms of maximum directivity is indicated by the concentric circles. The graph shows a respectable level of gain over most of the horizontal angles, with gains ranging from 100% to 50%, with the mark for 180° showing the least amount of increase. This is because of the interruption caused by the feedline, as well as the ground's role in shielding radiation travelling in the backward direction. The front cross-sectional view is indicated by the directivity graph of φ with θ=90°, portrayed in Fig. 15. The gain in terms of maximum directivity indicated through concentric circles. The graph illustrates the various vertical directions in which the design is capable of transmitting.

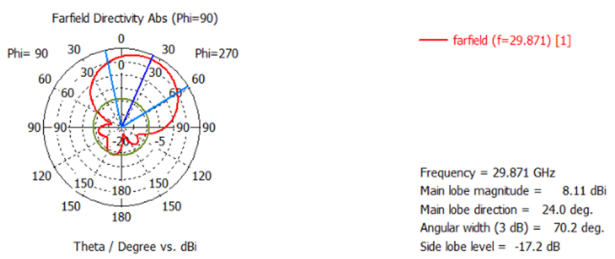

Fig. 13. Farfield Pattern of Proposed Antenna

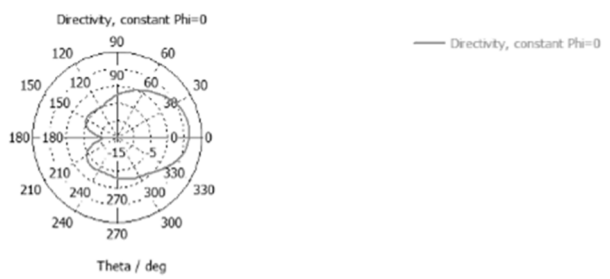

Fig. 14. Top Cross-Section of Radiation Pattern of Proposed Antenna (θ/φ=0°)

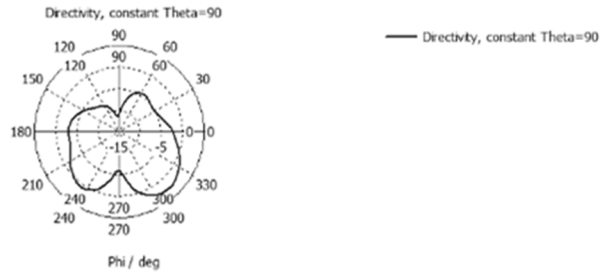

Fig. 15. Front Cross-Section of Radiation Pattern of Proposed Antenna (φ/θ=90°)

The maximum difference in gain is equal to 75% of the total gain.

The existence of feed is responsible for the fact that the gain is at its lowest point at an angle of 90°.

Despite this, the graph demonstrates that the design can transmit successfully in all vertical directions. Fig. 16 is an illustration of the three-dimensional radiation pattern, which demonstrates how the design is directed. When compared to transmission in all other directions, an antenna's directivity indicates its capacity to send signals in a specific direction. A design's directivity and beamwidth have a very tight relationship with one another.

The angular breadth over which an antenna may transmit in an effective manner is referred to as the beamwidth of the antenna. Both factors are inextricably linked to the implementation of the design.

Unidirectional antennas need a narrower beamwidth while yet maintaining a high level of directivity in one direction. On the other hand, antennas that must be omnidirectional or even bidirectional may have to make concessions in terms of their directivity in one direction to achieve a wider beamwidth. As shown in Fig. 16, the level of directivity is shown to be at its highest on the axis labelled "+ve Z," and it drops off significantly as one moves in the other direction. According to the graph, the design is capable of transmitting information successfully in all directions except for θ=180° and φ=90°. This is because the feed and ground are present.

VI.4. Performance of VSWR

While transmission of current occurs through the line, the current forms standing waves throughout the transmission line. The Voltage Standing Wave Ratio (VSWR) is the ratio of the maximum voltage that the standing wave can have to the minimum voltage it can have.

The value of the VSWR indicates how well the design can make use of the power that is being supplied to it. Additionally, it indicates the amount of power that is being reflected from the antenna to the transmission line.

Therefore, the VSWR and S_{11} have a tight relationship, which is represented by Equation (8). In an ideal world, the VSWR would be 1 if the design were to perform ideally. The VSWR of the design must be closer to 1 for most applications.

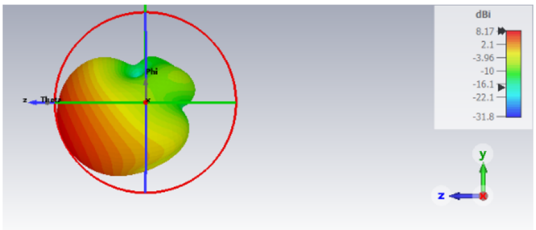

Fig. 16. 3D Radiation Pattern of Proposed Antenna

On the other hand, this is very dependent on the design parameters, the operating circumstances, and the uses of the design:

$$VSWR = \frac{1+\sqrt{S_{11}}}{1-\sqrt{S_{11}}} \tag{8}$$

As can be seen in Fig. 17, the design achieves the optimal value of VSWR, which is 1 when measured at the resonant frequency. On the other hand, it has been shown that across the bandwidth, the VSWR varies up to a maximum of 1.8. This is because there is now an air gap between the two pieces. Because of the very irregular and nonuniform nature of the electrical characteristics of air gaps as substrates, it is impossible to account for them in any way other than via modelling. As a result, the design approach has been carried out to guarantee that the design is working appropriately. Most patch antennas have higher VSWR values owing to the overall inefficiency of their design. However, the values for this design are acceptable for use under operational settings.

VI.5. Comparison of Results

Table III lists a comparison of the proposed design with other designs at similar frequency range. Table III makes it very evident what the purpose of the enhancements, particularly the incorporation of slots and the addition of an air gap, was meant to achieve.

Because of the air gap, the bandwidth has been increased to a respectable 3 GHz, and the dielectric constant of the substrate has been lowered, which has enabled a very low reflection coefficient of -51 dB to be achieved. Because of the slots, the standard patch fields have been transformed into a multidirectional field, which enables broadband transmission in both the horizontal and vertical planes. According to the findings, the slot fields and the patch fields have been superbly merged with one another to the point where they mutually complement one another and make it possible to modify the radiation pattern.

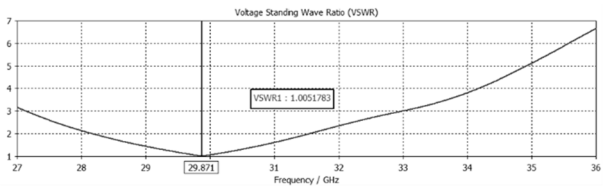

Fig. 17. VSWR Performance of Proposed Antenna

TABLE III
COMPARISION OF DESIGN

Parameter	Proposed Design	[38]
Resonant Frequency (GHz)	29.87	28.3
Bandwidth (GHz)	3	2.2
Gain	8.24	2.6
S_{11} (dB)	-51.75	-11
Directivity (degrees)_	7	5
VSWR	1	1.58

VII. Conclusion

The design that was suggested has a wide bandwidth of operation and a multidirectional radiation pattern. The modified patch antenna displays results such as a gain of 8.24, for a reflection coefficient of -51.75 dB, at a resonant frequency of 30 GHz. This gain is achieved while maintaining a VSWR of 1. This modified patch antenna exhibits excellent results for parameters such as gain, VSWR, and reflection coefficient. The radiation pattern of the antenna indicates a large beamwidth with a minimum directivity of 75% gain. Due to the design's omnidirectional transmission, with high gain all around, the design is ideal for OFDM based MIMO antenna arrays. To get the best results, the modifications that were made to the traditional patch model have been perfected and included in this new antenna structure. As future work, extra 'C' shaped slots can be added to enhance bandwidth and radiation pattern. Due to these modifications and results obtained, this research work meets MIMO-OFDM systems with 5G standard. Hence the proposed antenna design is recommended to employ in the MIMO-OFDM system for 5G applications at 30 GHz.

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