DESIGN OF A HIGH GAIN MULTI BAND SLOTTED MICROSTRIP PATCH ANTENNA FOR WIRELESS APPLICATIONS

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ABSTRACT

The microstrip patch antenna is effectively utilized in cutting-edge wireless communication systems, such as fifth generation (5G) applications. Using only one band of an antenna is not enough to offer a variety of wireless services. The main goal of this planned project is to create a multi-band microstrip patch antenna that can cater to various wireless services, ultimately lowering the antenna's cost and size.

The primary aim of this research is to enhance the gain of the microstrip patch antenna significantly by incorporating slots into a single patch, which is a widely used structure in 5G antennas. This empirical study was conducted using the HFSS High Frequency Structure Simulator, specifically focusing on the slot dimensions. FR-4 is a material used as a substrate that helps in lowering expenses. Therefore, multiband microstrip patch antennas containing slots provide a small, adaptable, and effective option for multiband wireless communication systems. Their capacity to operate across various frequency ranges and increased data transfer capacity make them essential elements in numerous uses, ranging from smartphones to Wi-Fi routers and more.

1. Introduction

Microstrip patch antennas have discovered great use in wireless communication structures, including cellular phones and radio frequency identification (RFID) gadgets[1]. Those compact antennas offer blessings, which include ease of integration, low profile, and value-effectiveness[3]. Whether or not embedded in a telephone or used for RFID tags, microstrip patch antennas play an essential role in enabling wireless connectivity.Microstrip patch antennas are widely preferred in wi-fi communique structures because of their low profile, price-effectiveness, light-weight layout, and compact form factor[9]. Their ease of fabrication, along with compatibility and conformance to circuit layouts, makes them an essential choice for present-day circuit improvement.With the non-stop advancement of technology and the transition in the direction of 5G networks, these antennas have additionally observed widespread use in 5G cellular communication devices[10]. Their function in ensuring seamless connectivity and green record transfer is pivotal in the ever-evolving panorama of wireless communication. Millimeter-wave (mm-wave) sets designated for 5G communication fall within ranges of 24.25–27.5 GHz, 27.5–29.5 GHz, 37–40 GHz, and 64–21 GHz[11]. Millimeter wave (mmWave) frequencies are situated in a specific segment of the electromagnetic spectrum and have special qualities that enable new and creative uses[12].

Here's a breakdown of the mmWave frequency range and its diverse uses:Specific Use Cases and Ranges:

5G Mobile Networks: Key driver of ultra-fast data speeds and low latency for applications like AR/VR, streaming, and cloud gaming. Typical ranges: 24 - 40 GHz and 57 - 86 GHz (varying by region and operator[13].Fixed Wireless Access: Delivers high-speed internet access in underserved areas wherefiberoptic deployment is challenging. Common bands: 28 GHz, 37 GHz, 60 GHz, and 70-80GHz[14].

Vehicle-to-Everything (V2X) Communication:Enables real-time communication between vehicles, infrastructure, and pedestrians for enhanced safety and traffic efficiency. Primarily uses 59 GHz and 79 GHz[15].

Automotive Radar: Crucial for advanced driver-assistance systems (ADAS) like collision avoidance, blind-spot detection, and adaptive cruise control. Oftenoperatesat 24 GHz and 77 GHz [16].

Security and SurveillanceMmWavescanners detect hidden objects and weapons, making them valuable for security checkpoints and airports. Ranges from 30 GHz to 96 GHz depending on the specific application[17].

Medical Imaging: Under research, exploring a broad range from 30 GHz to 300 GHz for non-invasive brain scans and tumor detection[18].

Industrial Automation: MmWavesensors ensure high-precision and speed in monitoring and controlling industrial processes. Primarily uses 24 GHz and 60 GHz[19].

ScientificResearch: Employs a wide range from 22GHz to 300GHz for studying material and molecule properties[20].

Entertainment: Utilizes the 60-80 GHz band for real-time gesture recognition in gaming and VR experiences[21].

The Future of mmWavetechnology continues to evolve, we can expect further advancements and wider adoption across various fields. The specific frequency ranges used for each application might also change based on technological improvements and regulatory changes[22].

The supply of the mm-wave spectrum, especially at those two frequencies, has significantly improved the feasibility of various mobile verbal exchange applications[23]. Researchers and engineers alike were captivated by the capability of harnessing those frequencies to construct sturdy and green 5G networks[24].

Researchers have also explored enhancing the radiation traits of microstrip patch antennas, spotting them as a great answer for modern-day 5G package[25]. Their ability to effectively transmit and receive indicators makes them a treasured asset within the ever-evolving landscape of wireless verbal exchange.

Microstrip patch antennas, even as extensively used, face an essential assignment: limited bandwidth [26]. But researchers have devised several effective strategies to conquer this hindrance. These encompass strategies inclusive of slotted-patch designs, the usage of substrates with better thickness or decreased relative permittivity, exploiting multiple resonances, and optimizing impedance matching[27]. By implementing those processes, microstrip antennas can obtain stepped-forward performance and cope with the demands of modern-day communication structures[28].

Concerning 5G, the confined bandwidth isn't always as critical a problem as it is in lengthy-distance communication packages running at lower frequency tiers. The precise traits of 5G networks, consisting of higher prices and shorter distances, allow for efficient usage of bandwidth[29].

In the context of the 5G era, the restricted bandwidth is less of a problem when it comes to communique packages running in remote environments at lower frequencies.The number one goal of the observer mentioned in this paper is to enhance the benefit and gain, directivity and bandwidth of the microstrip patch antenna designed for 5G cell phones running in the mmwave frequency band.In contrast to prior research, the study described in this paper aims to create a microstrip antenna with a sole patch configuration functioning at 26 and 28 GHz mm-Wave 5G frequencies[30]. The article utilizes the slotted-patch technique to achieve a notable enhancement in antenna gain and directivity. The reflection coefficient, Voltage Standing Wave Ratio (VSWR) and efficiency, along with other radiation characteristics, are intended to be enhanced without sacrificing bandwidth[31].

In comparison to prior research, the study designated in this paper makes a speciality of the improvement of a microstrip antenna presenting an unmarried patch structure optimized for operation on the 26 and 28 GHz mm-wave 5G bands[32]. The proposed method leverages a slotted-patch technique to decorate antenna gain and directivity extensively. Moreover, the research pursuits to beautify other radiation traits, consisting of the reflection coefficient, voltage standing wave ratio (VSWR), and overall efficiency, all at the same time as ensuring a sufficiently extensive bandwidth. This revolutionary painting contributes treasured insights to the sector of antenna layout and overall performance optimization[33].

2. Antenna designs and simulation results

Rectangular patch antennas are commonly used for their simple design and ease of analysis and fabrication, the antennas proposed in this study employ a rectangular patch with two L shape slotted in the patch.[31] All antennas are built on a rectangular FR-4 epoxy substrate with 20 mm,16.5 mm and 0.6mm thickness. The relative dielectric permittivity is 4.4 and the loss tangent is 0.01.For more information about FR-4 epoxy .The dimensions that are used for the patch are 10 mm for length and 9 mm for width where the patch is fed by a (50 ohm) microstrip line.

This paragraph presents an optimum dimensions, geometrical structures, and simulations results obtained from the antenna design [11]. To optimize the dimensions of each design, a parametric study was performed using the parametric sweeps provided by the HFSS simulator.The results show us the listed parameters : the reflection coefficient (S11), the bandwidth, the gain, the VSRW .

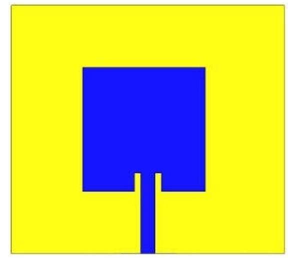
So in the design we have a pair of L-slots that our study began with.Based on the previous three design simulations and their performances the final design is being made with meeting the requirements.

The final design consists of two L-slots with four stages of designing as shown in the below.

Stage 1

In the first stage a patch is taken into consideration where the shape of the patch is rectangular as it supports a variety of wireless applications.

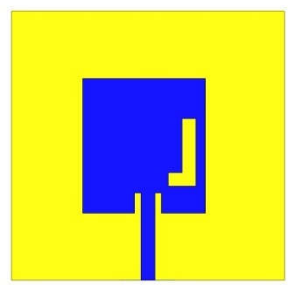
Hence, we have introduced a rectangular patch of dimensions of length 10 mm and width 9 mm(fig 1.1). The substrate that is taken the design is FR-4 epoxy as it shows simple and compact structure with a good gain.



(Fig 1.1)

Stage 2

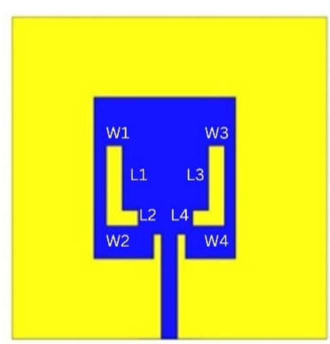
The firstL-slot is introduced to the left of the microstrip feed line. The results which we obtained by placing the L slot here is giving the best results so the dimensions of the vertical line of L are length 4mm, width 1mm and the horizontal line of L are length 1mm,width 2 mm respectively. After the simulation of the L1 slot the (fig1.2) is the result which we get.



(Fig 1.2)

Stage 3

To improve the stage 1 design and to meet the requirements of the multi band here another L-slot is introduced to the right of the microstrip feed line(fig 1.3). By placing the same L slot opposite to the L1 slot with same dimensions that is vertical line of L (right) are length 4mm, width 1mm and the horizontal line of L are 1mm, width 2 mm respectively [11].



(Fig 1.3)

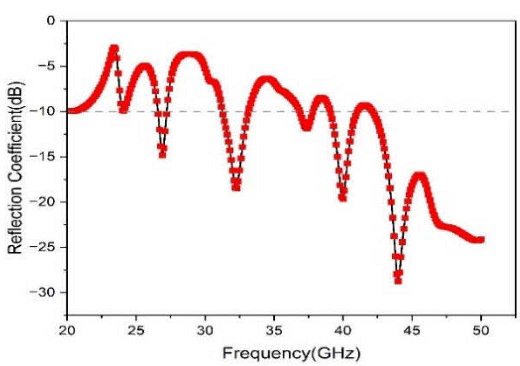
The below table shows us the dimensions (length and width) of the patch and slots (table 1.1):

Dimensions	Value(mm)
Patch length	10
Patch width	9
L1	4
W1	1
L2	1
W2	2
L3	4
W3	1
L4	1
W4	2

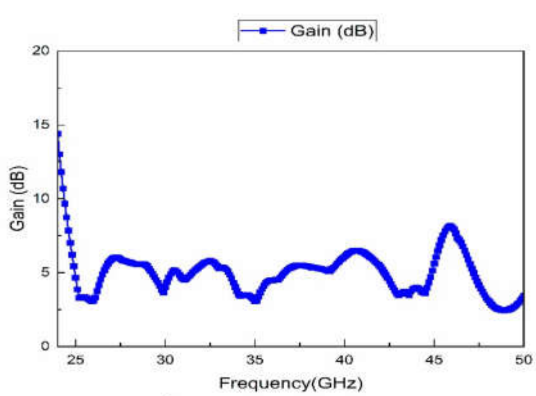
(Table 1.1)

Stage 4

After evaluating the design and getting satisfied with its results, we moved forward to investigate about the frequencies in the results. Futhermore,in final stage of design we have obtained four frequency bands at 27GHz, 32GHz, 40GHz and 44GHz (fig:2.1)with peak gains of 6dB, 5dB, 6dB and 3dB respectively (fig 2.2).



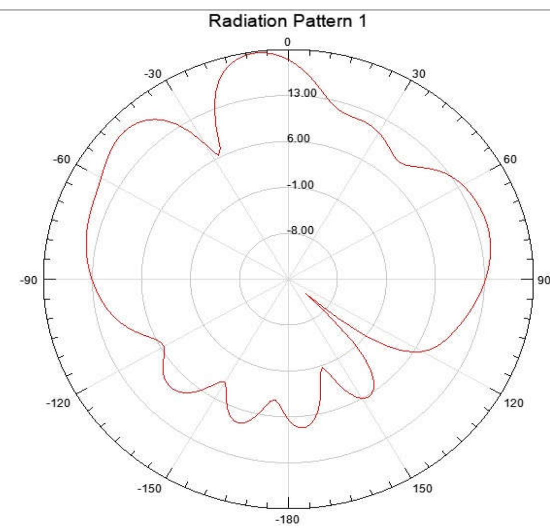
(Reflection coefficient and frequency plot fig 2.1)



(Gain and frequency plot fig 2.2)

Radiation pattern :

The radiation pattern of an antenna describes the directional properties of its radiation in three-dimensional space[17]. It illustrates how power is radiated or received by the antenna in different directions. Radiation patterns can be omnidirectional, directional, or even bidirectional, depending on the antenna type and design[19]. They are typically represented graphically in polar or rectangular coordinates, showing signal strength as a function of angle from the antenna's axis. These patterns are crucial for understanding antenna performance, coverage, and interference characteristics in various applications, such as telecommunications, radar, and wireless networking.Antenna radiation patterns describe how electromagnetic energy is emitted or received by an antenna in different directions. They can be omnidirectional, radiating equally in all directions, or directional, focusing energy in specific directions[12]. Key features of radiation patterns include the main lobe, which represents the primary direction of radiation, and side lobes, which are smaller lobes occurring in other directions[19]. Beamwidth, gain, and polarization are important characteristics depicted in radiation patterns, influencing coverage, directionality, and efficiency of the antennaUnderstanding radiation patterns is essential for designing and deploying antennas in various applications, from wireless communication networks to radar systems, to optimize performance and minimize interference.



(Radiation pattern fig 2.3)

The parameters are listed below with exact values for return loss (S11), Gain, Bandwidth(table 1.2):

Parameters	Value
S11(return loss) (dB)	26.9, 32.3, 40, 44
Gain(dB)	6, 5, 6, 3
Bandwidth	0.7, 1.8, 1.9, 2.8

(Table 1.2)

3.Comparing between the proposed and previous antenna designs

By comparing with previous work, we have developed multi band which is shown that all the frequency bands are lying between the mm wave frequency range used for wider applications[1].The below results compare the performance of our proposed antennasagainst a collection of previous designs [3].Since all the studies till now related to Millimeter wave have used Rogers as their substrate but in the proposed antenna the substrate is FR-4 epoxy where a significant improvement of bands are being shown with stages.

4.Conclusion

This paper introduces a microstrip antenna featuring a slotted rectangular patch, designed to address the rising need for reliable 5G mobile communication services.The main objective of this research was to attain a multiband, significant antenna gain, reflection coefficient and efficiency, while maintaining a broad bandwidth at two specific 5G frequencies. The initial collection was constructed with only one L slot. It achieved excellent outcomes in gain, directivity, and other factors, yet additional enhancements were needed to outperform all other designs previously discussed. The second group examined LL-slot combinations along with varying slot shapes. They demonstrated superior outcomes compared to the initial batch. Design #4 was an improved variation of Design #3 with further optimization done on the middle-slot dimensions and the spacing between L and I slots. The highest level of gain obtained from both antennas at 27 and 40 GHz band was over 6dB. While the gain and directivity did not significantly increase when moving from stage 2 at 32 GHz resonance, the radiation parameters such as VSWR, efficiency, and bandwidth showed noticeable enhancements. In conclusion, stage 3 is considered the top antenna option for 5G millimeter wave (mm-Wave) applications in our study. Nonetheless, the improvements in gain and directivity obtained from the four LL-slotted designs suggested here surpass those obtained in previous studies.

In conclusion, our findings indicate that the suggested slotted microstrip patch antenna designs are suitable for 5G wireless applications, meeting the primary design requirements of simplicity, affordability, and compactness. In the future, it is recommended to explore various combinations of alternative slot shapes or consider utilizing antenna arrays to enhance certain antenna radiation properties, specifically focusing on improving bandwidth as mentioned in this paper.

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