Design and Simulation of Hexagonal Microstrip Patch Antenna for 5G NR n79 Band Communications

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***Abstract*—**The rapid development of modern wireless communication technologies prompts the need for compact and reliable antennas capable of supporting stable and efficient signal transmission in different types of systems. In this work, a hexagon-shaped microstrip patch antenna is designed for microwave wireless communication applications. The presented antenna is reveals resonance at 4.53 GHz which can be used in wireless communication and sensing applications. By introducing hexagonal geometry, the surface current distribution is enhanced and a good amount of impedance matching with superior radiation characteristics than conventional microstrip patch antennas was achieved. The antenna is designed on FR-4 substrate with a dielectric constant of 4.3 and a thickness of 1.6 mm in order to create a small and inexpensive structure. The provided antenna has good return loss, VSWR, and stable radiation for the newest wireless communication applications, according to the findings of the design performance simulation using the CST studio suite.

Index Terms*—*Hexagonal microstrip patch antenna, wireless communication, 4.53 GHz, FR-4 substrate, CST Studio Suite, impedance matching, return loss, VSWR & gain design and simulation.

I. INTRODUCTION

Wireless communication systems have changed dramatically in recent years since the arrival of fifth generation (5G). Such systems require antennas that are compact and efficient, and with stable performance at higher frequencies. Due to its low profile, simple fabrication, and compatibility with printed circuit processing techniques, the microstrip patch antenna—has been so popular lately. Microstrip antenna is a typical metallic patch over insulating base with reference plane on the other side. Antenna performance depends on the geometry of the patch, how it is being fed, and the substrate material being used. To improve the bandwidth, return loss, and impedance matching modified geometries are needed to be studied, even traditional geometries are available. To implement 5G Wireless Communications which is responsible for high data rates, low latency and good connectivity features, we require frequency range of 4 to 5 GHz. You are taught about antenna design through this frequency, which is a term that must support efficient radiation while preventing the total reflection of inductive concerns.

In this paper, a novel hexagonal microstrip patch antenna is designed to work at proximity of 4.4 GHz. An aperture feeding set-up with two slots, which is capable of altering the current distribution and enhancing impedance matching, is introduced in this design. The antenna is modeled, and simulated in CST Microwave Studio, fed with an input signal for performance analysis in terms of return loss and VSWR. The following sections are as follows: The literature review is said in Section II. Section III says the antenna design and it's approach. The simulation results are said in section IV. Section V concludes the study.

II. LITERATURE REVIEW

Many methods, including changed geometries and slot-based topologies, have been researched for the design of microstrip patch antennas in order to meet the performance requirements of next-generation unguided communication media. Specific improvements in performance have been researched with an emphasis on compact antenna structure and enhanced impedance matching suitable for 5G communication bands (4–5 GHz). A thorough description of microwave and antenna basics which is especially focused on the operation of microstrip antenna was presented by Pozar [1]. His research contributed to insight about how parameters of the substrate, like dielectric constant and thickness affect resonant frequency and bandwidth. These findings helped in the selection of the FR-4 substrate for the antenna design presented In [2], Wong reported both compact and broadband microstrip antenna configurations and pointed out that bandwidth enhancements as well as improved impedance behaviors can be obtained by altering the geometry of the radiating patch. This is why the antenna is designed in a hexagonal shape instead of normal rectangular patch.

Finally, James and Hall [3] presented in-depth research of microstrip antenna structures where they demonstrated that other configurations could enhance radiation characteristics as well as current distribution. Their work provides motivation to switch from polygon-patch based designs to a more efficient design.

Garg et al. [4] presented practical microstrip antennas design methodology and highlighted realistic dimension calculation and feeding techniques. Their study informed the initial design approach and parameter selection used in this work.

Maci and Gentili [5] studied multi-frequency behavior in patch antennas by modifying patches. These results stressed the need for control over current paths, a characteristic related to the slot-based tuning in this design.

Guo et al. [6] have also investigated into slot-coupled microstrip antennas and reported that including slots can enhance both impedances matching with receiving circuits as well as bandwidth. Thus, the previous results served as a solid foundation for using slot features close to the feed zone with the proposed design antenna.

The study [7] by Kishk evaluated the in-slot antenna configuration and claimed that placement of slot plays a crucial role on its performance. It was also helpful in understanding how the slot geometry can be used for improving return loss and matching.

Wong and Luk [8] have investigated a number of small antenna designs oriented towards wireless communication, with compactness and performance efficiency highlighted. The goal of designing a compact antenna for modern wireless systems was supported by their work.

In 4G/5G applications, Bao and Ammann [9] introduced a large number of compact antennas and said that change in antenna structure improves the performance without enlarging the volume. This idea informed the use of a compact design in this work.

Zhang et al. Antenna design for 5G applications was addressed in [10] demonstrating the necessity of maintaining stable behavior within the sub-6 GHz band. The frequency range of 4.4 GHz seems appropriate for this design, as shown by their work.

Wu et al. [11] highlights printed antenna design considerations for future wireless networks and repeat the need of proper design optimization to obtain good impedance matching in addition with radiation performance, particularly when it comes to high-frequency applications.

Ikram et al. Geometric modification along with slot techniques is found to be beneficial in achieving better return loss and VSWR, as reported by [12] for wideband microstrip antennas designed for sub-6 GHz set of the 5G technology. This directly aligns with the design methodology in our proposed antenna.

It can be safely concluded from these studies that geometry modification as well as slot integration significantly boost the antenna performance. Concluding all these insights, the below content presents design of hexagonal microstrip patch antenna for 5G NR n79 Band Communications with microstrip feedline at either side, operating in the frequency of 4.5 GHz.

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III. DESIGN AND ANALYSIS

The CST studio suite software was used to develop and simulate the hexagonal microstrip patch antenna. The final overall geometry was developed using theoretical calculations and simulation-based step by step optimization. The initial dimensions were determined using standard microstrip antenna design formulas. Then, the changes were made for impedance matching and resonance at 4.5 GHz.

A. Substrate Selection

The substrate is FR-4 as it is low cost and the availability range is wide. The dielectric constant (εr) is 4.3, and the tan delta is 0.02. The substrate thickness (h) is 1.6 mm. This selection of metrics is to get better performance and to get resonance at 4.5 GHz. The active layer and metal backing's usual copper thickness is 0.035 mm. The FR-4 is a sensible selection even though it has moderate dielectric losses at higher frequencies, to design smaller antennas focusing on practical use in wireless communication systems.

B. Patch Geometry and Dimensions

A Hexagonal antenna with usage of two microstrip feeding technique on either side is our design. The patch is designed in such a way that it radiates efficiently and small in size for the selected frequency. The main structural parts of the antenna are detailed as follows:

1) **Hexagonal Patch Body:** For optimized radiation while maintaining compact size Hexagonal shape is chosen. It also provides proper current distribution. Hexagonal patch is the main radiating element whose width is 17.5 mm and height is 20.58 mm.

2) **Microstrip Feed:** The edge of the patch is attached with a microstrip feed line like a neck attached to the head. The feed line is guiding current from feed to the active layer giving good excitation to the antenna.

3) **Inset Feed Structure:** Consider the hexagon as the central component of an antenna. It has a neck like structure for microstrip feed line at the bottom that connects to the power supply. This neck is important serving as a channel for the electricity powering the antenna. There are two little vertical gaps of a width 2 mmh adjacent to that neck. These gaps let the antenna to reach the precise channel and make sure the energy flows properly without any signal loss or degradation.

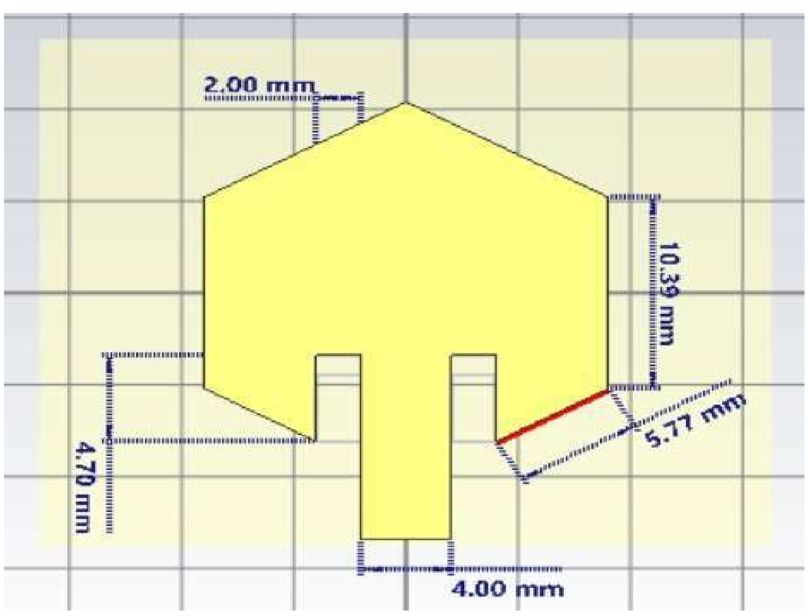

Fig. 1. Dimensions of the proposed hexagonal microstrip patch antenna as simulated in CST Microwave Studio. Key dimensions: hexagon side = 5.77 mm, vertical height = 10.39 mm, inset feed width = 2 mm, inset feed length = 4.70 mm, feed width = 4 mm, and feed length = 5 mm.

C. Design Equations

The first layout of designed modified hexagonal microstrip patch antenna is done using analytical expressions, then simulation-based tuning. The operating frequency was focused on 4.4 GHz, which is intended for the wireless 5G communication. Resonant frequency for a hexagonal microstrip patch is obtained from an analogous circular patch model. One such widely used method is based on the concept of effective radius that helps with simplification for analysis. The frequency of resonance is therefore given by:

$$f_r = 1.8412 \times c / (2\pi \times aeff \sqrt{\varepsilon r})$$

where c - light's speed in free space and εr is the substrate relative permittivity. The effective radius includes the fringing field effects at the patch edges, which slightly enlarge the antenna electrical size.

The hexagonal patch dimensions were estimated with standard design equations for the recommended layout focusing on 4.4 GHz. The patch itself was modeled as 5.77 mm wide and 10.39 mm tall, with a feed width of 4 mm and slot spacing that measured at 2 mm. Through simulation, these dimensions were further fine-tuned to yield resonance about 4.52 GHz.

On FR-4 substrate (h = 1.6 mm, εr = 4.3) with a natural impedance of 50 Ω, the microstrip feed line is designed as shown in Fig.1. The theoretical value of feed width can be taken as the actual increase accordingly (ca. 4 mm). This feed structure also employs a rectangular inset slot (2 mm width and 6 mm depth) for improving impedance matching and reducing mismatch loss at an centre frequency of approximately 4.52 GHz.

IV.RESULTS AND ANALYSIS

The proposed hexagonal microstrip patch antenna in electromagnetic was evaluated using CST Microwave Studio. A transient solver based on the generalized FDTD was used for the simulation. Berenger Layer boundary conditions were defined in the simulation medium to absorb outgoing waves and prevent reflections. A edge port was used to stimulate the antenna at the feed point. The performance of the design was studied by checking the S parameters and the VSWR characteristics throughout a broad range from 1 GHz to 6 GHz which allowed us also to see the complete behavior very close around our operating frequencies.

A. VSWR (S11) Performance

Fig. 2 shows the simulation S11 (VSWR Value) curve results for the antenna. It can be observed that the antenna has a dominant resonance at around 4.51 GHz with minimum return loss of about −13 dB. This means that the majority of power going into the input is radiated, and very little gets bounced back.

The −10 dB bandwidth spread out the resonant frequency confirms that the antenna efficiently works in 4.4–4.5 GHz range and can be used for 5G wireless communication applications. The presence of a clear-cut dip in the S11 curve also indicates good reflection less condition between 50-Ω supply line and the active layer.

A inset feed near the microstrip feed line of our antenna leads to a resonance curve with a unique shape. These inset feeds create new paths for current that enhance impedance matching and shift the eigen frequency by a small amount. Consequently, the antenna reaches stable performance in the regarded frequency range.

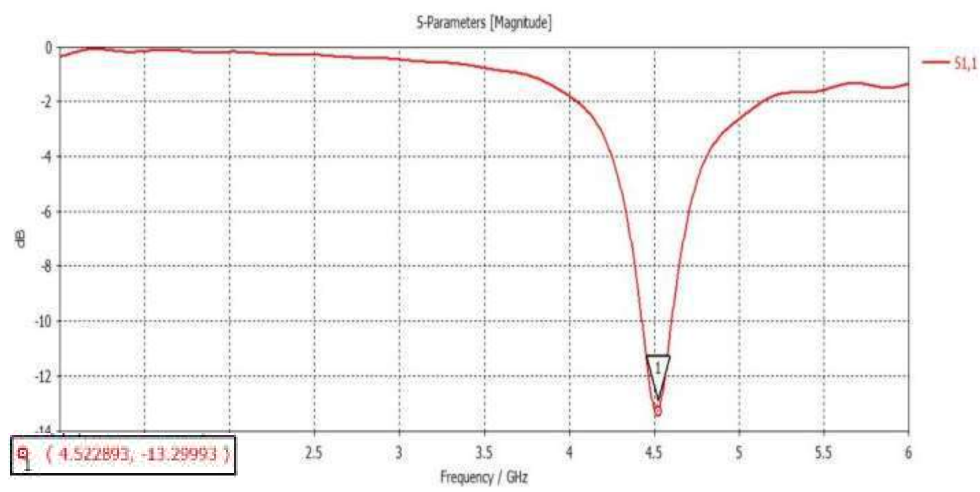

Fig.2. Simulated S11 (return loss) of the proposed hexagonal shaped antenna. The marker indicates S11 = −13.29 dB at f = 4.5 GHz.

B. VSWR Performance

The frequency-dependent Voltage Standing Wave Ratio (VSWR) is shown in Fig. 3. This results in a minimum VSWR of around 1.5 at the eigen frequency of the antenna, which is about 4.5 GHz. This is an indication of better reflection less condition between the supply line and active layer. VSWR is still very close to the limited level (VSWR < 2) through the operating frequency range, indicating that more power will be transmitted in the target band of the 5G with low reflection.

At resonance, low VSWR means a small reflection coefficient, which means that most of the input power reaches the antenna instead of being reflected. VSWR is indeed significantly high when moving away from the resonance frequency, which is not surprising considering that this antenna was built for narrowband operation. With a VSWR of less than 2, the overall performance achieved by the antenna indicates good matching and makes it suitable for 5G wireless communication applications in frequencies near to 4.4–4.5 GHz band.

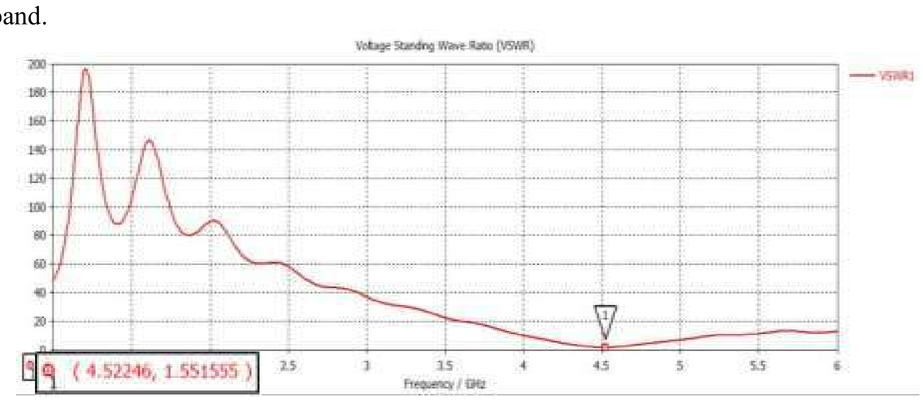

Fig. 3. Simulated VSWR of the proposed hexagonal lock-shaped antenna. The marker indicates VSWR = 1.55 at f = 4.52 GHz.

C. Performance Summary and Comparison

Table I compares the simulated performance of the proposed modified hexagonal microstrip patch antenna with some selected antenna designs reported in literature operating frequency range of 4–5 GHz. Table I: Looking at designs side by side with references Table I shows that the antenna works much better than the reference designs.

TABLE I. Comparison of Antenna Interested with Referenced Structures, Operating at 4.5 GHz

Reference	Frequency (GHz)	S11 (dB)	VSWR	Patch Shape
[4]	4.50	−10.5	1.82	Hexagonal
[6]	4.40	−9.6	2.10	Rect.+ slot
[11]	4.30	−8.9	2.25	Rectangular
This Work	4.51	−13.0	1.50	Modified Hex-Shaped

The result return loss of around −13 dB is lower than the reported values in others works thus revealing a lower signal reflection. Also, mulated VSWR around 1.5 is lower than those of the compared antennas which confirms better impedance matching. The enhanced performance has been primarily attributed to the adjusted hexagonal geometry in addition with the dual-slot configuration at the feed region. This allows controlling both the current distribution and improving power transfer efficiency. Meeting the requirements of 5G wireless Communication applications in 4.5 GHz band the proposed design gives better performance in comparison with regular rectangular antenna.

CONCLUSION

Here we have provided a well-designed and analyzed hexagonal microstrip patch antenna for 5G NR n79 band communications at the frequency range of 4.5 GHz for the applications of 5G wireless communication. A compact hexagonal radiating patch and double inset feed structure is introduced for impedance matching and improvement of performance. According to the simulation, at a frequency of about 4.52 GHz, this antenna has approximately −13 dB return loss and nearly 1.5 VSWR values with clean energy transfer to load along with good impedance matching needed for an optimal circuit design. The designed antenna's mismatch loss and VSWR performances are better than already available designs. The design is straightforward, compact, and can be easily manufactured using standard PCB methods, making it easy for practical applications. Fabrication and experimental validation of the antenna can also be performed in future work. There are also some useful techniques that make the antenna perform better in all aspects, like increasing the gain, improving the bandwidth, and many such things.

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