Design of Sub 6GHz Antenna for 5G Applications

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Abstract: — Multi-band designs with wide bandwidth and minimal interference are becoming more and more popular as the requirement for tiny and efficient antennas in 5G, satellite communication, radar, and the Internet of Things increases. Using a FR4 substrate ($\varepsilon r = 4.4$), a novel multi-band antenna measuring $26.5 \times 27 \times 1.6\ mm^3$ is demonstrated in this study. With a bandwidth of 673.1 MHz and a return loss of -23.33 dB, resonance is reached at 4.1 GHz. With return losses of -35.95 dB at 15.3 GHz and -21.69 dB at 9.1 GHz, it also operates over a wide frequency range between 9.1 and 15.3 GHz. Simulation findings confirm that it is appropriate for high-speed wireless networks and radar applications, and it is tuned for impedance matching and radiation efficiency.

Keywords— semicircular patch, impedance matching.

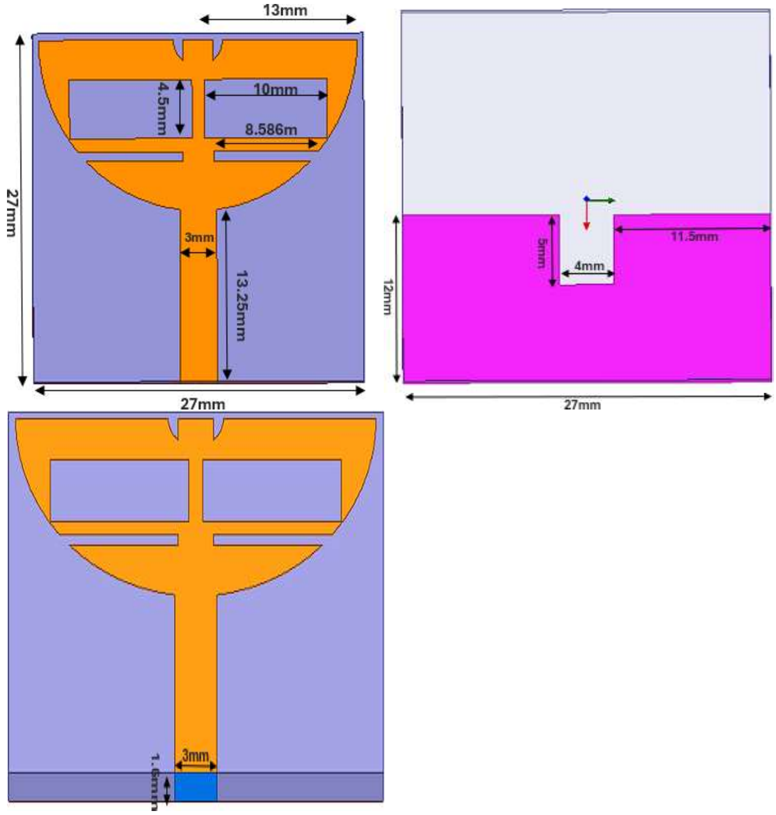
1. Introduction

With fifth-generation wireless communication becoming more and more popular, there is a greater need for advanced antenna systems that can provide faster data rates, lower latency and continuous connectivity. Of the many frequency bands designated for 5G, the sub-6 GHz spectrum is crucial due to its superior propagation characteristics, lower atmospheric attenuation, and reliable coverage. This has stimulated a great deal of research in the creation of small, effective and wide-band antennas that fit contemporary wireless systems [1]. The development of tiny and flexible antennas has become critical for their use in a variety of applications, including wearable electronics, IoT devices, and high-speed communication networks. Recent advances in flexible inverted L-shaped antennas have exhibited considerable increases in isolation and stability under mechanical deformation, making them extremely appropriate for MIMO configurations in sub-6 GHz 5G networks [2]. Moreover, multi-band MIMO antennas have been extensively studied to enable continuous operation at sub 6 GHz, Ku-band, and millimeter-wave (mm Wave) frequencies. Decoupling techniques and defected ground structures (DGS) are used to reduce mutual coupling and improve overall antenna performance [3]. Assuring good isolation and efficiency while preserving compactness for wearable and portable applications is one of the fundamental difficulties in sub- 6 GHz antenna design. DGS-based decoupling approaches have shown excellent improvements in isolation and bandwidth expansion in four-element MIMO antennas, making them a promising alternative [4]. Additionally, ultra-wideband MIMO antennas designed for WLAN, X-band, and sub-6 GHz 5G applications have demonstrated improved impedance bandwidth and resilient radiation properties, which makes them perfect for multipurpose wireless systems [5].

Nature-inspired antenna designs have been investigated recently to increase efficiency while maintaining compactness. Leaf-shaped antennas have demonstrated improved gain, better impedance matching, and superior broad band performance, which makes them ideal for sub-6 GHz 5G applications [6]. In a similar vein, triple-band MIMO antennas with L-shaped microstrip designs have been tuned to function at 3 GHz,
4.1 GHz, and 5.2 GHz, which makes them useful for connected car communications, smart city networks, and fixed wireless access [7]. In MIMO antenna systems, mutual coupling is still a significant issue, especially when several radiating elements are positioned close to one another. To address this problem, scientists have implemented stub loaded structures, slot-etched ground planes, and isolation enhancing components to guarantee consistent performance at sub-6 GHz, Ku-band, and mm Wave frequencies [8]. Dual band microstrip antennas for X-band and Ku-band applications also incorporate triple-slot patch topologies to improve impedance matching and radiation efficiency, which makes them appropriate for high-data-rate communication systems [9]. Theoretical modeling has been essential in enhancing the design of sub-6 GHz antennas, even beyond practical study. To preserve high efficiency and ideal impedance characteristics for 5G communication applications, electrically compact patch antennas have been developed using equivalent circuit models [9]. Key performance parameters such return loss, gain, isolation, and overall efficiency are examined in the evaluation of the suggested design using full wave simulations and experimental validation. This study adds new knowledge to the development of satellite communication antennas and next generation 5G by tackling important issues such mutual coupling reduction, bandwidth optimization, and radiation efficiency improvement. Due to its efficiency across two distinct frequency bands, the proposed dual-band antenna design is suitable for Ku-band and sub-6 GHz applications. Its sub-
6 GHz 5G transmission compatibility is ensured by its resonance at 4.1 GHz and bandwidth of approximately 687 MHz. Its operating range is further expanded to encompass Ku-band frequencies, which have a large resonance around 15.3 GHz and extend from 8.1 GHz to 16 GHz. The antenna uses strategically positioned slot based decoupling techniques and defective ground structures (DGS) to enhance isolation and impedance matching. It is a promising candidate for future wireless and satellite-based communication applications because of its optimized design, which ensures stable performance throughout both bands, low return loss, and high radiation efficiency.

2. Proposed Antenna Design

The antenna is made on a FR4 substrate that is 26.5 mm x 27 mm x 1.6 mm in size, has a dielectric constant of 4.4, and is 1.6 mm thick. A feedline, a modified ground plane, and a semi-circular radiating patch with carefully placed slots to enhance current distribution and impedance matching make up the construction. The top width of the patch is 13 mm, while the feedline is 13.25 mm long and 3 mm broad. To improve signal propagation, two horizontal slots measuring 10 mm and 8.586 mm are inserted. Additionally, a 4.5 mm high slit is included for improved radiation efficiency and electrical length adjustability. The ground plane has a rectangular notch at the bottom that is 3 mm wide and 1 mm high, following a partial ground structure is depicted in Figure 1. The ground plane, which is 12 mm high and 27 mm wide, has a balanced horizontal section (11.5 mm) and a central notch (4 mm wide, 5 mm deep) to maximize radiation patterns and impedance matching, enhancing total antenna performance.



(a) (b) (c)

Figure 1. The proposed antenna design (a) radiating plane (b) ground plane (c) excitation port

3. Result and Analysis

3.1 S parameter Plot:

Primary resonances at 4.1 GHz with-23.33 dB, 9.1 GHz with-21.69 dB, and 15.3 GHz with-35.95 dB are confirmed by the Return Loss S11 plot, which also shows that the proposed multiband antenna has impedance matching. The semicircular patch, the partial ground plane, and a 3x13.25-millimeter feedline all affect the 4.1 GHz resonance. Horizontal slots of 10 and 8.586 millimeters and a 4x5 millimeter ground plane notch improve the 9.1 GHz resonance. An extended 11.5-millimeter ground plane and semicircular patch are used to create the 15.3 GHz resonance, which guarantees the best high-frequency performance.

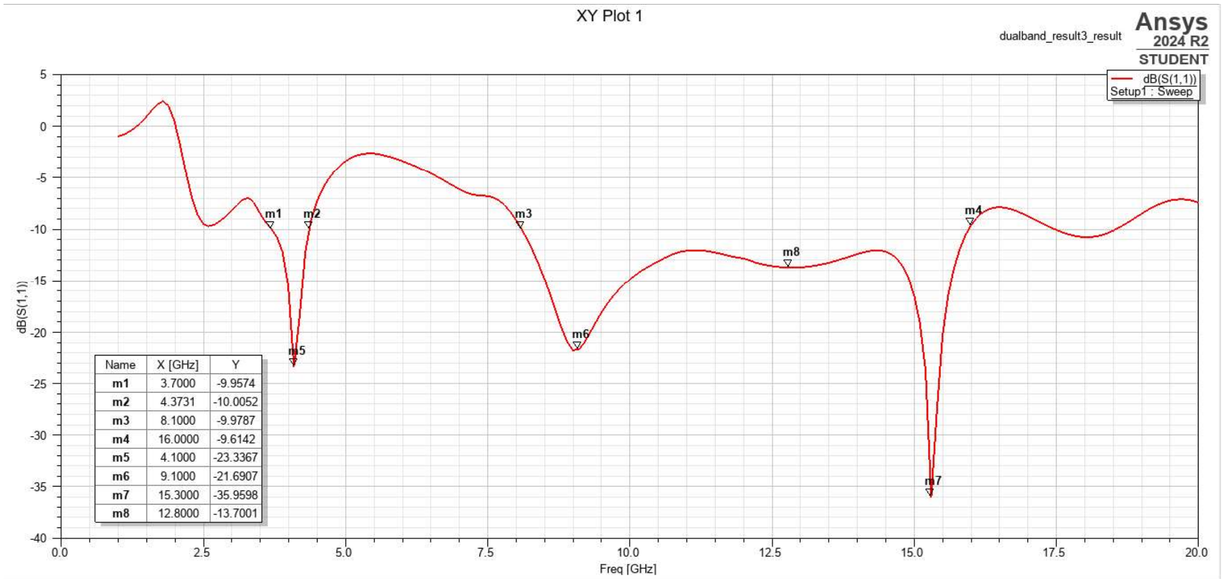


Figure 2. Simulated S-parameter plot of the proposed antenna

3.2 Gain:

The proposed antenna's 3D radiation pattern at 15.3 GHz is depicted in Figure 3 gain plot, which shows gain values ranging from-30 dB to a peak of 3.79 dB. The antenna's energy distribution in various directions is represented by the red regions, which show maximum gain, and the blue portions, which show minimal emission. To ensure effective signal propagation, the semi-circular patch and slot. design contributes to a multi-lobe radiation pattern. Gain and impedance matching are improved by the 11.5-millimeter extension and partial ground plane. A steady energy distribution is confirmed by the color changes from red to green, which shows a progressive drop in radiation intensity. The antenna's outstanding radiation performance at 15.3 GHz, with a peak gain of 3.79 dB, is confirmed by the gain plot. For high-frequency applications, structural alterations such as the ground plane and slot adjustments effectively mold the radiation pattern.

Table 1 Gain values at different Frequencies.

Frequency (GHz)	Gain(dB)
4.1	27.15
9.1	1.64
12.8	2.56
15.3	3.79

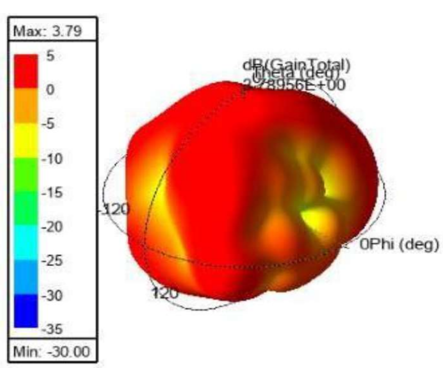
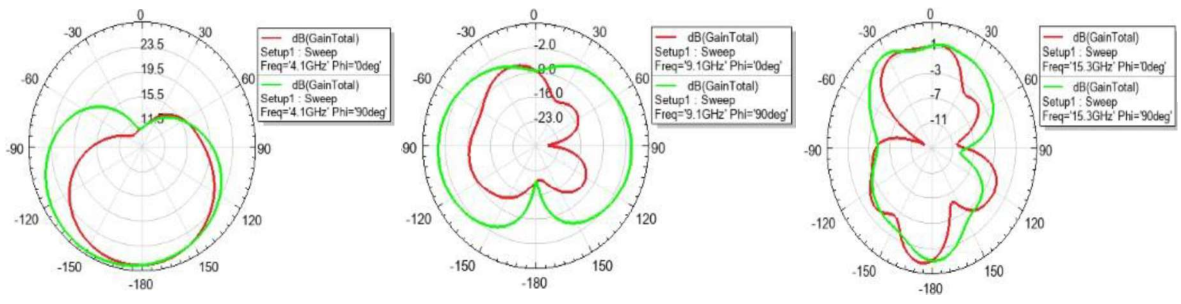


Figure 3. Gain plot of proposed antenna at f = 15.3 GHz.

3.3 Radiation Pattern:

Figure 4 at 4.1 GHz shows a constant radiation pattern with an equal gain distribution in both planes, demonstrating effective energy radiation. Figure 4 displays many lobes at 9.1 GHz. While the Phi = 0° plane exhibits greater gain in specific directions, the Phi = 90° plane has a larger dispersion. Fig 4(c) at
15.3 GHz shows a more directional pattern with notable fluctuations, with the Phi = 0° plane displaying more focused gain and the Phi = 90° plane maintaining wider coverage. These patterns demonstrate the antenna's directional qualities at different resonance frequencies.

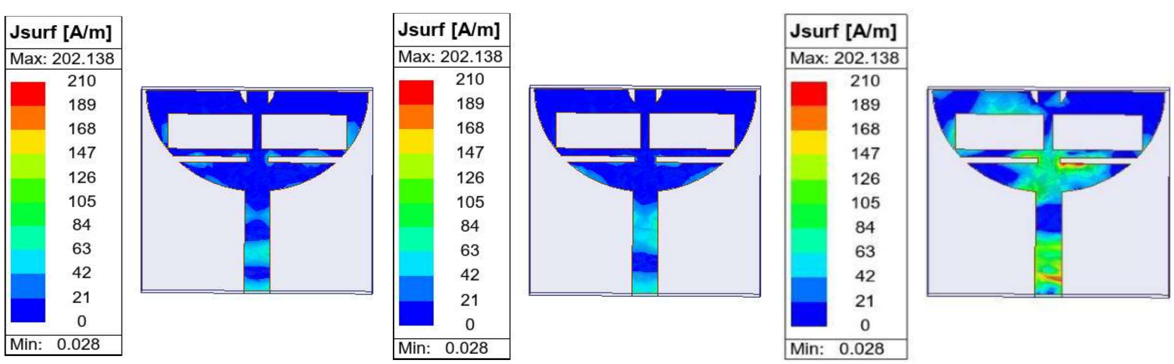


(a) (b) (c)

Figure 4. Radiation pattern of the proposed antenna at (a) 4.1 GHz (b) 9.1 GHz (c) 15.3GHz

3.4 Current density:

The surface current distribution of the suggested multi-band antenna at 4.1 GHz, 9.1 GHz, and 15.3 GHz is shown in Figure 5 respectively. Impedance matching is impacted by the current being concentrated along the feedline and lower patch edges at 4.1 GHz. Resonance characteristics are shaped by the current shifting towards the horizontal slots at 9.1 GHz. At 15.3 GHz, the feedline and ground plane contribute very little to the maximum current density along the top patch edges and slots, suggesting that the patch structure is mostly responsible for higher-frequency resonance. These findings validate that the patch shape affects higher frequencies, the feedline affects lower frequencies, and the slots affect mid band resonance.



(a) (b) (c)

Figure 5. Current density of the proposed antenna at (a) 4.1 GHz (b) 9.1 GHz (c) 15.3GHz

4. Conclusion

The proposed dual-band antenna, with dimensions 26.5 mm × 27 mm × 1.6 mm, performs well at 4.1 GHz with a bandwidth of 673.1 MHz and shows broadband response between 9.1 GHz and 15.3 GHz. The use of slot-loaded structures and defected ground plane improves impedance matching and bandwidth with return loss values of-23.33 dB, -21.69 dB, and-35.95 dB at important frequencies. The antenna has stable radiation properties, with gain of 1.64 dB at 9.1 GHz, 2.56 dB at 12.8 GHz, and 3.79 dB at 15.3 GHz. Surface current distribution verifies that the semicircular patch and the modified ground plane are responsible for resonance performance optimization. The design provides wideband operation, impedance matching consistency, and effective radiation properties over its operating frequencies.

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