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Design of a Wide Band Circular Patch Antenna for WiMAX, C-Band and 5G Sub-6 GHz Communication Applications

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ABSTRACT

The Advancement of Fifth-generation of Wireless Communication System Necessitates Sophisticated antenna designs capable of supporting increased band-width, Higher data rates, and low latency. This Paper Invokes the design and analysis of Circular Patch Antenna for WiMAX and 5G C-Band applications Operating within the 5G Sub – 6GHz Spectrum across frequency bands of N77 (3.3-4.2GHz), N78 (3.3-3.8GHz), N79 (4.4-5GHz). As communication network evolve towards higher frequencies and faster data rate. The Antenna is outlined on FR-4 Epoxy material in co-ordination with Dimensions of 30mm x 24mm x 1.6 mm. This antenna focuses on Single element circular patch antenna with S-parameters, VSWR, Radiation Pattern are analyzed in both 2D and 3D plots. The design and simulation were conducted using CST Studio Suite. The results demonstrate that the proposed antenna is a promising candidate for Sub-6 GHz 5G and WiMAX communications, offering enhanced performance, compact size, and reliable operation.

Keywords: 5G Sub-6GHz, Wireless Communication, WiMAX, C-Band, Circular Patch Antenna.

1.INTRODUCTION

The Introduction of fifth-generation (5G) technology, which promises notable gains in data throughput, latency, and connectivity over its predecessors, wireless communication has reached a crucial turning point. The sub-6 GHz spectrum, in particular the 4.4 to 5 GHz region, has become a viable option among the different frequency bands allotted for 5G because of its advantageous propagation characteristics and compatibility with current network infrastructure. This frequency range's antennas are essential for enabling dependable, fast wireless communication. The emergence of 5G that provides minimal latency and allows a larger volume of data transfer has become one of the backbones for wireless communications [1]. In 2019, the numbers of 5G mobile connections were 5 million which is expected to be 577 million by the year 2023 [2]. Compared to the current generations, 5G wireless communications is characterised with distinctive metrics including a data transmission rate of Gbps, a latency time of millisecond, a very high traffic volume density, ultra-dense connections, enhanced spectral energy, cost effectiveness [3]. It is therefore thought that frequency spectrum below 6 GHz also known as sub-6 GHz band serves as the primary frequency band for the commissioning of the 5G, especially for the N77 (3.3-4.2 GHz), N78 (3.3-3.8 GHz) and N79 (4.4 - 5.0 GHz) bands. For 5G communication, the ITU (International Telecommunication Union) has allocated microwave bands (3.4-3.6 GHz and 5-6 GHz) [4-5]. Furthermore, sub-6 GHz antennas need to be made to work with other service bands including current Long-Term Evolution (LTE) antennas. As a result, a 5G antenna needs to be able to span existing LTE bands as well as Wi-MAX, WLAN, and sub-6 GHz bands. Because of its low profile, lightweight design, affordability, and simplicity of integration into microwave integrated circuits (MIC) or monolithic microwave integrated circuits (MMIC), the microstrip patch antenna is a smart choice among the available antenna options.[6] The necessity of combining several wireless communication standards into a single personal wireless device has been highlighted by the emergence of wearable sensors and body- centric communication systems. Wearable multiband antennas that can operate across many frequency bands are required to meet the requirements of these communication protocols. These antennas must specifically cover the 5-GHz WLAN IEEE 802.11a and 5.15–5.825 GHz for WLAN and 5.3578–5.9519 GHz for 5G unlicensed band [7]. The antenna works well with WLANs operating at 2.4 and 5.8 GHz. Electromagnetic bandgap (EGB) unit cells with pin diodes for frequency selectivity are another practical design.[8] The essential part of every wireless communication system that creates the connection between the transmitter and the receiver is the antenna. Antenna design for 5G base stations and mobile phones is consequently in high demand as the 5G communication technology has been deployed in several nations worldwide [9]. Because of its small size, symmetrical emission pattern, and simplicity of production, the circular patch antenna is a promising option for 5G sub-6 GHz applications. This antenna type, which predominantly operates in the 3.3 to 3.8 GHz range, is ideal for small-cell base stations and user devices when performance and space are crucial. In dynamic mobile situations, its circular design facilitates efficient polarisation control, supporting both linear and circular polarisation. Furthermore, circular patch antennas have consistent radiation properties and can be tuned for increased gain and bandwidth through the use of parasitic components or slotting. Because of these characteristics, the circular patch antenna is a good option for fulfilling the sub-6 GHz spectrum performance requirements of 5G communication [10]. This study presents the design and optimisation of a circular patch antenna for sub-6 GHz 5G applications. Here The proposed antenna which has dimensions of 24 x 30 x 1.6 mm, is simulated using feed and circular excitation. At 4.7 GHz, the design shows a high impedance. Future meetings will address the design, outcome, and conclusion analysis

2.ANTENNA DESIGN AND GEOMETRY

There are three primary steps in the antenna design process. First a ground plane antenna is designed with dimensions of 24 x 30 mm, and has a dielectric constant of 4.4, and is 1.6 mm thickness, Next copper-annealed material is used to design the ground plane. Table gives the antenna's dimensional details, whereas Figure 1 shows the proposed designs. Commercially available CST software was used to construct the recommended antenna. The proposed antenna covers frequency range of WiMAX (3.4-3.6GHz), 5g C-band (3.7-4.3GHz), and 5G Sub-6GHz (N77, N78, N79).

2.1 ANTENNA DESIGN

1.Groundplane:

In the Initial we design Ground-plane with dimensions of 24mm x 30mm with copper annealed material as shown in figure A

2.Patch:

Figure B shows a simple circular patch antenna with a feed line in the first stage with dimensions of 24mm x 30mm are designed where the goal is to reach the frequency bands.

3.Patch with stubs:

Figure C shows a circular patch antenna with two stubs extended other side of circular head with outer radius of 1.5mm.

4.Patch with stubs and slots:

The original basic patch antenna is further altered to produce a second resonance at 4.6 GHz. To do this, rectangular slots are positioned in the centre of the circular patch. As shown in figure D the patch antenna operated in a broad frequency range.

5.Ground plane with slots

At this stage we constructed the Ground plane with slots and the dimensions of 0.8mm x 4mm as shown in figure E.

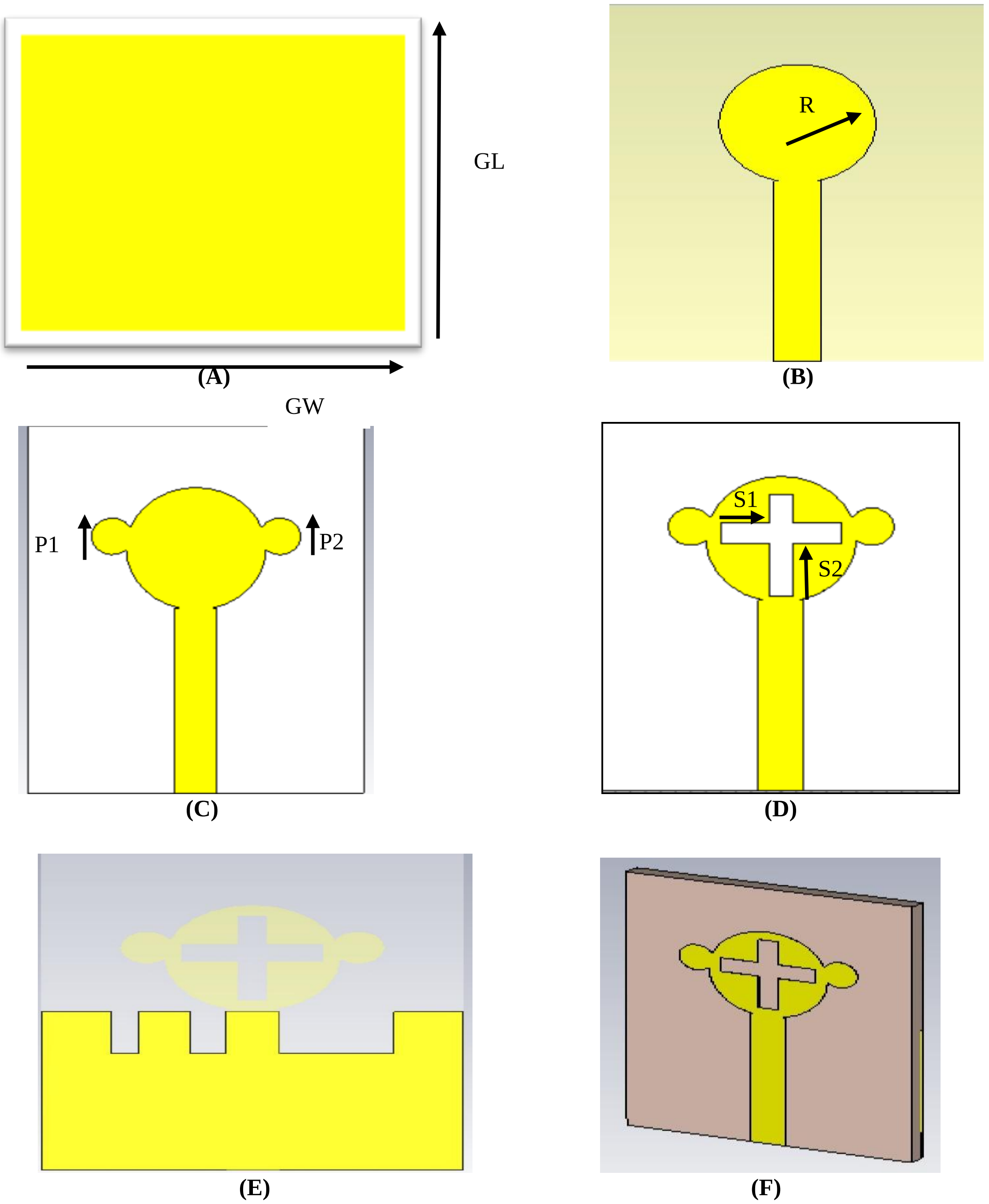


Figure 1: Evaluation of Proposed antenna at Different phases (A) ground plane (B) Circular patch (C) Patch with Stubs (D) patch with stubs and slots (E) Ground plane with slots (F) Perspective view

Table of contents:

Parameter	Gw	GL	P2
Value(mm)	24	30	1.5
Parameter	Sw	SL	S1
Value(mm)	24	30	0.8(W)
Parameter	FL	Fw	4(L)
Value(mm)	15	1.5	S2
Parameter	R	P1	4(W)
Value(mm)	5	1.5	0.8(L)

RESULTS

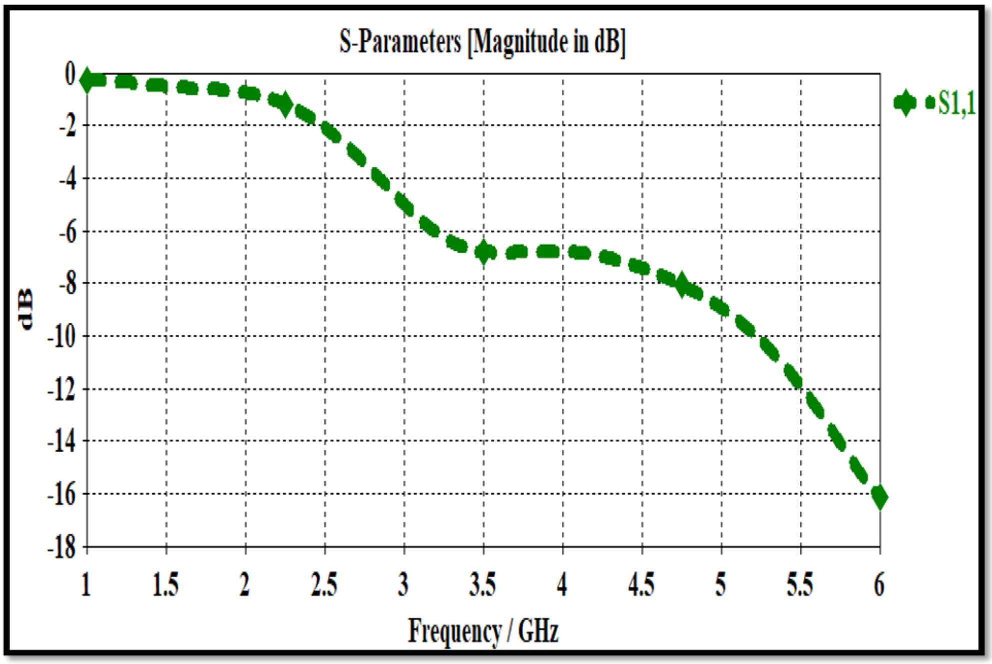


Figure (2A)

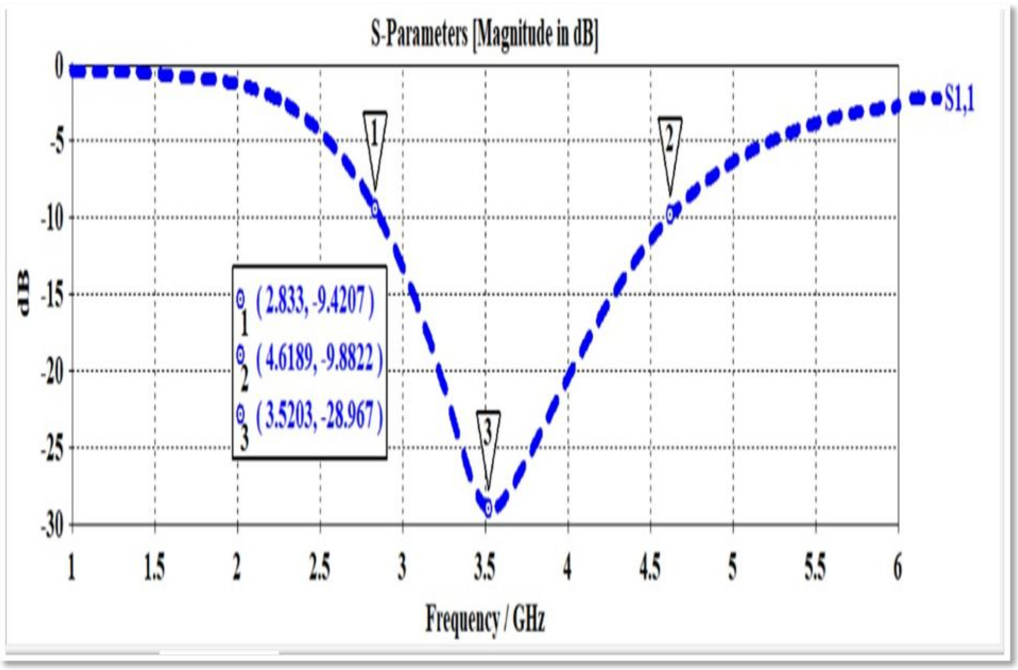


Figure (2B)

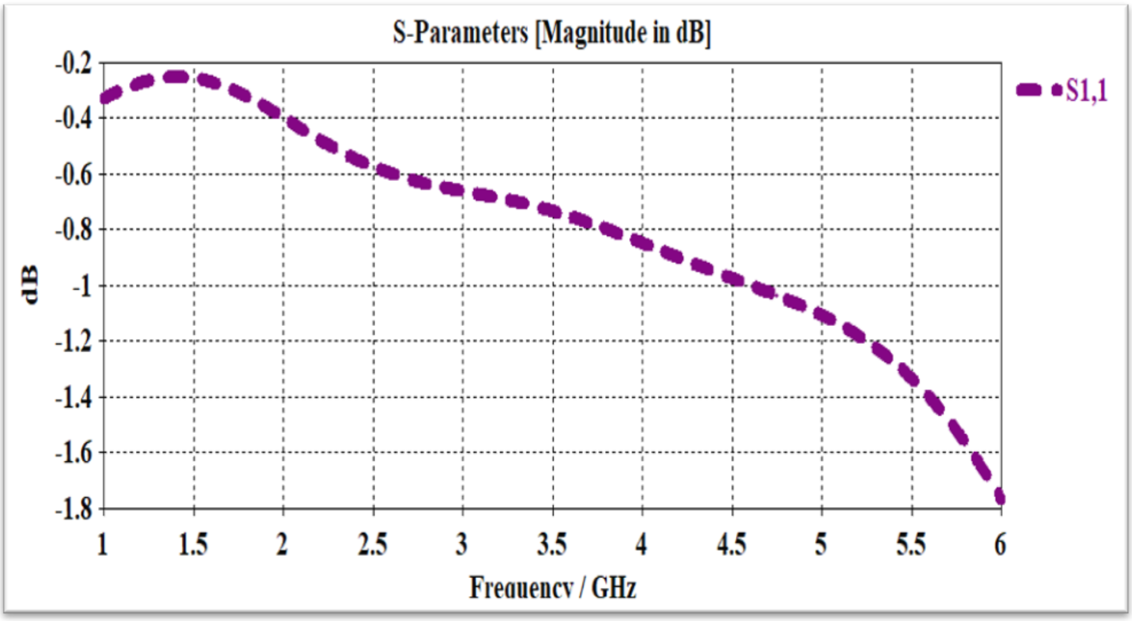


Figure (2C)

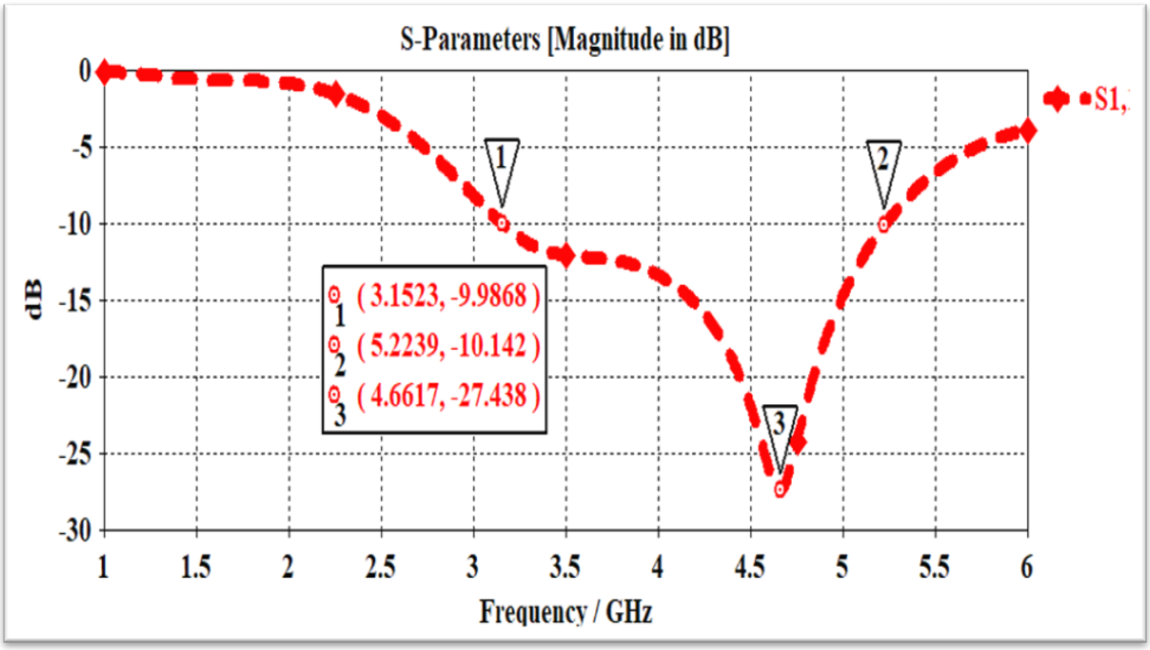


Figure (2D)

Figure 2 S-parameters at different stages of design (2A) Circular patch (2B)patch with stubs (2C) Patch with Stubs and slots (2D) Proposed design

A. Description of S -Parameter Results

Figure (2.A) shows the magnitude response of the S-parameter S11measured in dB over a frequency range of 1 GHz to 6 GHz. The parameter represents the input reflection coefficient, indicating how much power is reflected back from the input port remains close to 0 dB, suggesting a high level of reflection and poor impedance matching. As the frequency increases, the magnitude of S11gradually decreases, reaching approximately -8 dB at 3.5 GHz and further dropping below -16 dB near 6 GHz. This trend indicates an improvement in impedance matching and reduced reflection at higher frequencies. The continuous decline highlights the device or system becoming more efficient at transmitting power as frequency increases.

The Labeled Figure 2B shows the plot of S-Parameters (Magnitude in dB) against Frequency (GHz), specifically showing the reflection coefficient (S11) behaviour of an antenna or RF structure. The x-axis represents frequency from 1 GHz to 6 GHz. The y-axis represents S11 magnitude in decibels (dB), ranging from 0 dB to -30 dB. Three significant resonance points are identified on the curve At 2.8571 GHz, the S11 value is -9.9063 dB At 3.5032 GHz, the S11 value drops to -28.862 dB, indicating excellent impedance matching and very low reflection. At 4.6249 GHz, the S11 value is -9.8096 dB. The curve shows a major dip at 3.5 GHz, suggesting that the antenna/system is optimized around this frequency with minimal reflection loss. The plot uses a thick blue dashed line to represent the data.

The Labeled Figure 2C Illustrates the S-parameter magnitude in dB for the transmission coefficient S21 across a frequency range of 1 GHz to 6 GHz. The curve, shown with a dashed red line, represents how efficiently power is transmitted from port 1 to port 2 of the network. The graph shows that S21 remains close to 0 dB in the lower frequency range, indicating minimal signal loss. However, there is a noticeable dip around the 3.5 GHz region, where the magnitude drops significantly, suggesting signal attenuation or a notch in the transmission. Beyond this frequency, the magnitude begins to recover. This behavior is often associated with band-stop or filter-like characteristics in RF/microwave circuit design.

The labeled Figure 2D shows a plot of S-Parameters (Magnitude in dB) versus Frequency (GHz). It specifically illustrates the reflection coefficient (S11) performance of an antenna or RF component. the frequency range on the x-axis spans from 1 GHz to 6 GHz. The y-axis measures the magnitude of S11 in decibels (dB), ranging from 0 dB to -30 dB. The plot indicates three key points where significant resonances occur At 3.1523 GHz, the S11 value is approximately -9.9868 dB. At 5.2239 GHz, the S11 value is around -10.142 dB. At 4.6617 GHz, the deepest resonance occurs with an S11 of about -27.438 dB, indicating impedance matching and minimal reflection.

B. VSWR

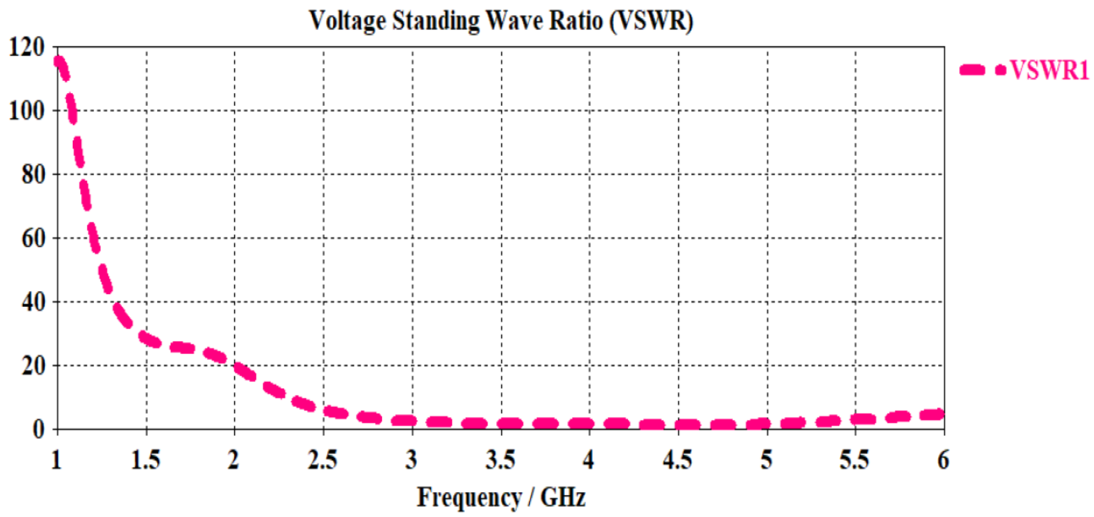


Figure 3

The Fig [3] presents a graph titled "Voltage Standing Wave Ratio (VSWR)" plotted against Frequency (GHz). The VSWR values are shown using blue dotted points labeled VSWR1.The frequency range extends from 1 GHz to 6 GHz along the x-axis. The VSWR values on the y-axis range from 0 to 120.At lower frequencies (~1–2 GHz), the VSWR values are extremely high, exceeding 100.As the frequency increases towards 3 GHz, the VSWR significantly drops, reaching values close to 1, which indicates a very good impedance match. Between 3 GHz and 5.5 GHz, the VSWR remains low and stable, suggesting that the antenna system performs well over this band. A slight increase in VSWR is observed beyond 5.5 GHz, indicating a minor degradation in performance at higher frequencies.

C. Surface Current Distribution

Surface current distribution in antennas refers to the way electric current flows on the surface of a conducting antenna when it is transmitting or receiving electromagnetic waves. This distribution is crucial because it directly determines the antenna's radiation pattern, input impedance, and efficiency. Surface current is the current that flows along the outer surface of a conductor due to the skin effect at high frequencies (e.g., in RF antennas). At high frequencies, currents tend to flow near the surface of conductors, leading to surface currents rather than volumetric currents. Surface current distribution varies with operating frequency; at resonance, standing wave patterns form.

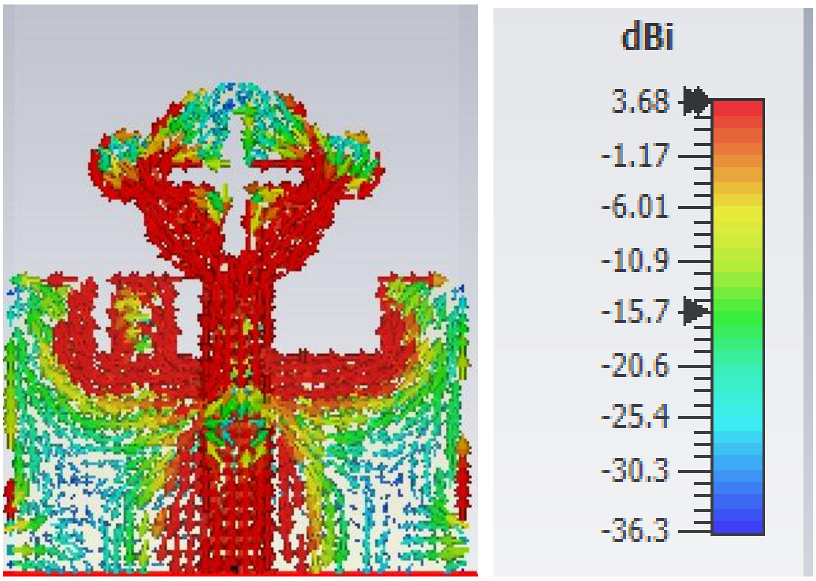
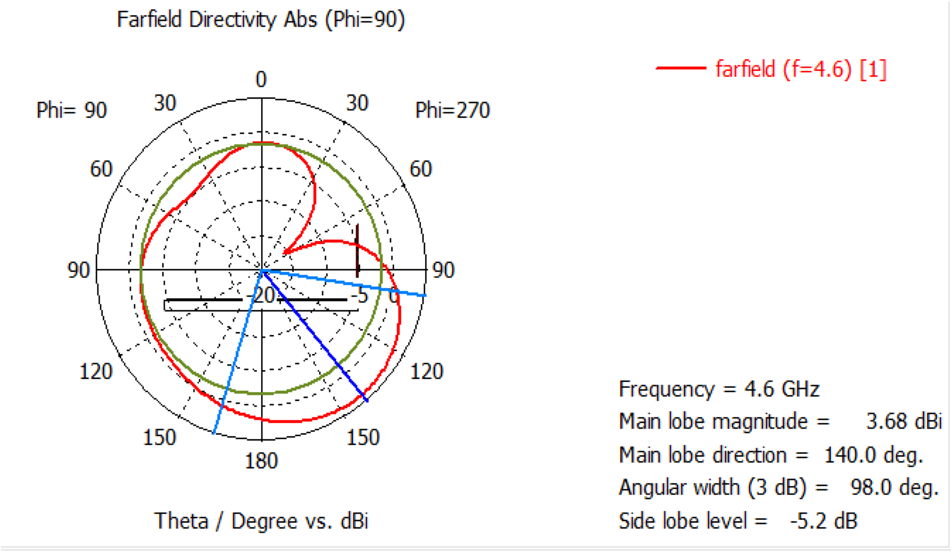


Figure 4

The figure above illustrates the surface current distribution of the proposed antenna at a specific resonant frequency. The color scale indicates the current density magnitude in A/m, with red regions representing higher surface currents and blue regions corresponding to lower current densities. It is observed that the maximum current concentration occurs along the feed line and the edges of the radiating patch, suggesting strong electromagnetic radiation from these areas. The distribution of surface currents highlights the active regions responsible for efficient radiation and impedance matching. The symmetry of the current distribution also indicates stable performance, and minimal undesired modes are excited, thereby ensuring reliable operation across the designed frequency band.

D. 2D Radiation Pattern



Theta/Degree vs dBi
Figure 5 Radiation Pattern of Port 1 at 4.6Ghz

The figure presents the 2D radiation pattern of the antenna at a frequency of 4.6 GHz, plotted in polar coordinates. The pattern illustrates the far-field directivity as a function of theta (in degrees) versus gain (in dBi). The main lobe is observed at an angle of 140°, with a peak gain of approximately 3.68 dBi. The 3 dB angular width of the main lobe is 98°, indicating a moderately broad beam. The side lobe level is measured at -5.2 dB, showing a good suppression of unwanted radiation in other directions. The radiation pattern confirms the directional behavior of the antenna, with a strong main beam and relatively low side lobes, suitable for targeted communication applications**.**

E. 3D Polar plot

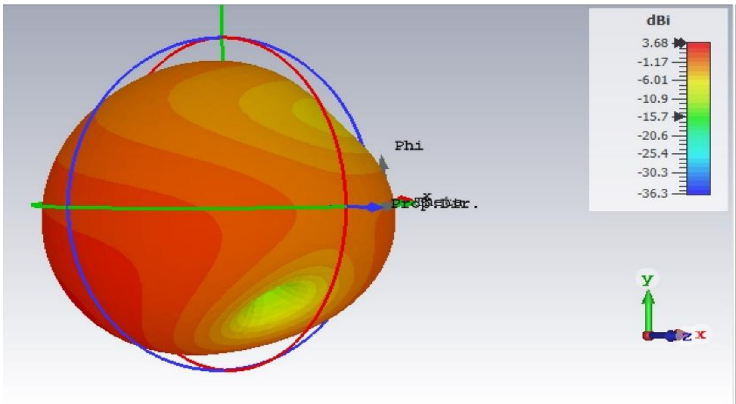


Figure 6 Simulated 3D plot at 4.6Ghz

Figure [6] shows the simulated 3D plot antenna at 4.6 GHz. The plot illustrates the spatial distribution of radiated power, with the color scale indicating the gain values in dBi. The maximum gain is observed near 3.5 dBi, corresponding to the red region of the plot, while lower gain values are indicated by green and blue areas. The radiation is predominantly directional, with a significant concentration of energy in a specific direction, ensuring effective transmission and reception. The 3D pattern confirms the antenna's ability to provide stable and focused radiation characteristics, suitable for applications requiring reliable directional performance.

CONCLUSION

We have presented a novel antenna design in this paper that is especially suited to the needs of 5G networks operating at sub-6 GHz. This antenna stands out for its distinctive design, which consists of a partial ground plane and a circular radiating element with a precisely placed slot pattern that resembles a positive symbol. This arrangement, which is printed on a 24x30x1.6 mm FR4 substrate, offers prolonged coverage between 4.4 and 5 GHz. The performance gains made possible by slot implementation in the antenna design are demonstrated by the examination of the S-Parameter (S11) and Voltage Standing Wave Ratio (VSWR) charts. The effectiveness of the suggested antenna design is demonstrated by the examination of the surface current distribution, 2D radiation pattern, and 3D radiation pattern. Strong current concentrations along crucial antenna construction segments are visible in the surface current distribution, suggesting effective radiation and appropriate impedance matching. Directional behaviour and low radiation losses are confirmed by the 2D and 3d radiation patterns at 4.6Ghz.

FUTURE SCOPE:

The design can also be extended to MIMO (Multiple Input Multiple Output) configurations to support massive MIMO deployment in 5G base stations, improving channel capacity and diversity. Furthermore, miniaturization techniques using metamaterials or fractal geometries can be employed to reduce antenna footprint without sacrificing performance, which is crucial for integration into compact wearable or IoT devices.

Declaration by Authors

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Conflict of Interest: No conflicts of interest declared.

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