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# Design and Analysis of Multi-Band Microstrip Patch Antenna for 5G Applications

**Pratyusha Pushadapu[1],Bhagya Rani Kasani[2],Boyina SasiKala[3]**

Assistant Professor,Department of ECE,Bapatla Women's Engineering College,Andhra Pradesh,India[1,2]

B.Tech Scholar,Department of ECE,Bapatla Women's Engineering College,Andhra Pradesh,India[3]

**Abstract:** This study presents the design and analysis of a microstrip patch antenna array operating at 3.6 GHz, within the Sub-6 GHz band designated for 5G communication systems. The proposed antenna is fabricated on an FR4 epoxy substrate with a thickness of 2.2 mm and a compact footprint of 70 mm × 70 mm. A five-element linear array configuration is implemented to improve gain and directivity. Impedance matching is achieved through a lumped port excitation with a feedline width of 27.18 mm. For far-field characterization, a radiation boundary of 90 mm × 90 mm × 35 mm is established. Performance evaluation across 3 GHz to 17 GHz demonstrates suitability for WiMAX and satellite communication applications.

**Keywords:** Microstrip Patch Antenna; Antenna Array; 3.6 GHz; Sub-6 GHz Band; 5G Communication; High Directivity; FR4 Substrate; Lumped Port Excitation; WiMAX; Satellite Communication systems.

## INTRODUCTION

Fifth-generation (5G) wireless communication systems represent a major advancement in modern telecommunications, addressing the increasing demand for high data rates, reliable connectivity, and low-latency services. The rapid growth of internet-based applications, high-definition multimedia streaming, and widespread use of smart devices has driven the need for more efficient communication technologies. Compared to earlier generations, 5G provides significant improvements in terms of Quality of Service (QoS), network capacity, spectral efficiency, data throughput, and latency.

A key distinction between 5G and previous generations, such as 4G, is the utilization of a broader range of frequency bands. This enables wider bandwidth availability and higher transmission speeds. The 5G spectrum is generally categorized into low band (below 1 GHz), mid band (sub-6 GHz), and high band (millimeter-wave frequencies). Among these, the sub-6 GHz band offers an effective balance between coverage and performance, while also ensuring compatibility with existing communication systems and reduced signal attenuation compared to millimeter-wave frequencies.Microstrip patch antennas are widely adopted in 5G systems due to their compact structure, low profile, lightweight nature, and ease of fabrication. These features make them suitable for integration into modern wireless devices. However, conventional microstrip antennas exhibit limitations such as narrow bandwidth, low gain, limited power handling capability, and surface wave losses.A typical microstrip patch antenna consists of a radiating patch and a ground plane separated by a dielectric substrate. Various feeding techniques are used to excite the antenna, which are broadly classified into contacting methods (such as coaxial probe and microstrip line feed) and non-contacting methods (such as proximity and aperture coupling).

The objective of this work is to design a compact rectangular microstrip patch antenna operating at 3.6 GHz for sub-6 GHz 5G applications, with acceptable gain and radiation performance.

### 2.Antenna Structure and Design Methodology

The proposed antenna consists of a radiating patch on the top layer, a ground plane on the bottom layer, and a dielectric substrate in between. The antenna is excited using a microstrip feed line. A rectangular patch geometry is selected due to its simplicity and stable performance.
The design procedure is based on standard analytical expressions, as described below:

**Step 1: Calculation of Patch Width (W)**

W = \frac{c}{2 f_r} \sqrt{\frac{2}{\varepsilon_r + 1}}
Where:
(c) = speed of light,
(f_r) = resonant frequency,

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($\varepsilon_r$) = dielectric constant of substrate

**Step 2: Effective Dielectric Constant (($\varepsilon_{eff}$))**

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left(1 + \frac{12h}{W}\right)^{-1/2}$$

Where:
($h$) = substrate thickness,
($W$) = patch width

**Step 3: Effective Length (L($_{eff}$))**

$$L_{eff} = \frac{c}{2 f_r \sqrt{\varepsilon_{eff}}}$$

**Step 4: Length Extension (($\Delta L$))**

$$\Delta L = 0.412h \cdot \frac{(\varepsilon_{eff} + 0.3)(W/h + 0.264)}{(\varepsilon_{eff} - 0.258)(W/h + 0.8)}$$

**Step 5: Actual Patch Length (L)**

$$L = L_{eff} - 2\Delta L$$

**Step 6: Ground Plane Dimensions**

$$L_g = L + 6h$$

$$W_g = W + 6h$$

**Step 7: Feed Line Design**

The feed point is selected to achieve an input impedance of 50 Ω.

**Characteristic impedance:**

$$Z_0 = \frac{60}{\sqrt{\varepsilon_{eff}}} \ln \left(\frac{8h}{W_f} + \frac{W_f}{4h}\right)$$

**Effective aperture area:** $A_{eff} = W \times L$
**Approximate antenna gain:** $G \approx (4\pi A_{eff}) / \lambda^2$

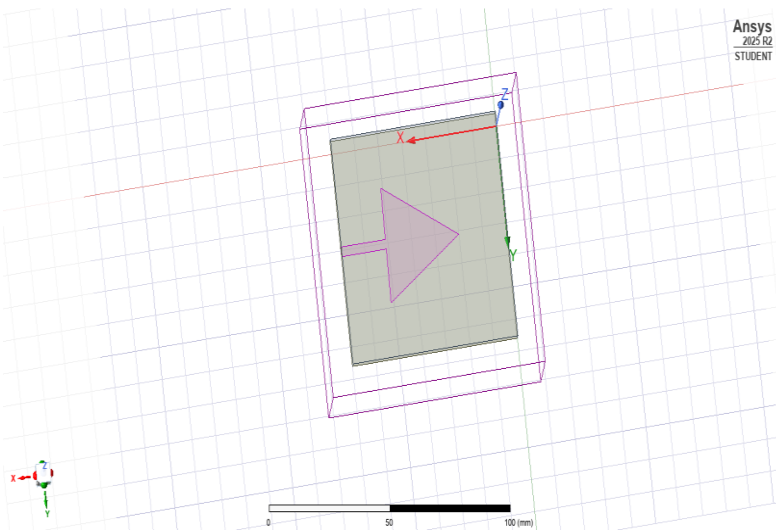

Figure 1(a):Structural View of the Proposed Antenna Design

 

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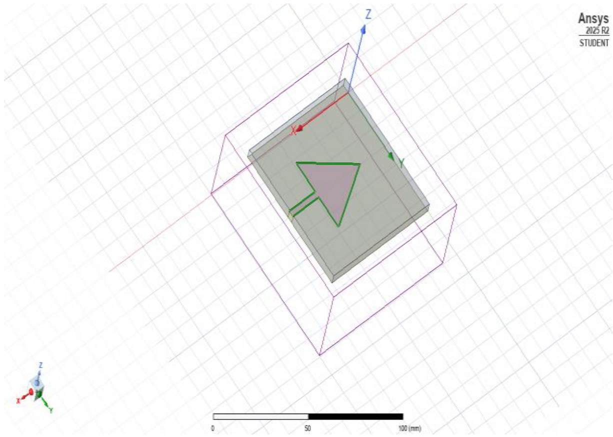


Figure 1(b): Complete HFSS Simulation Setup of the Proposed Patch Antenna

A detailed HFSS model has been developed to analyze the proposed microstrip patch antenna. In this configuration, a triangular radiating element is printed on a finite rectangular dielectric substrate, while a ground plane is provided on the opposite side to support proper radiation behavior. To accurately replicate real-world operating conditions, the structure is surrounded by an air-filled radiation boundary that minimizes reflections and simulates free-space propagation. The coordinate system illustrated in the setup defines the antenna orientation along the X, Y, and Z axes. This modeling approach enables precise electromagnetic characterization of the antenna performance.

Table 1:The Designed Antenna Dimensions

| **Parameters** | **Value in (mm)** | **Parameters** | **Value in (mm)** |
|---|---|---|---|
| Ground plane Width | 70 | Ground plane Thickness | 0 |
| Substrate Width | 70 | Substrate Thickness | 2.2 |
| Feed line Width | 25.2 | Feed line Thickness | 0.2 |
| Lumped port Width | 2 | Lumped port Thickness | 2.1 |
| Radiation boundary Width | 90 | Radiation boundary Thickness | 35 |

**The Antenna Results**

The proposed multi-band microstrip patch antenna demonstrates strong performance characteristics suitable for 5G communication systems. The design achieves good radiation efficiency, supports a wide operating bandwidth, and enables stable operation across multiple frequency band

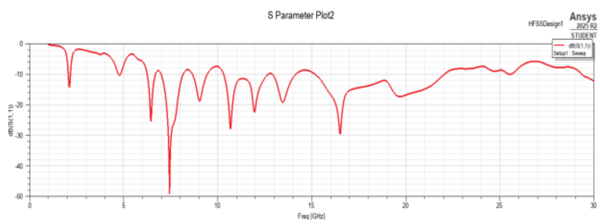


Figure 2:S-Parameter (Return Loss) Plot of Multi-Band Microstrip Patch Antenna for 5G Applications

The $S_{11}$ response illustrates how the reflection coefficient varies with frequency for the designed antenna. Two distinct resonant frequencies are observed at 15 GHz and 22 GHz, where the $S_{11}$ values are approximately -10dB, respectively. These points represent the primary operating bands of the antenna. The overall response spans from 2 GHz to 30 GHz, confirming that the antenna supports a broad frequency range. These results indicate that the antenna is capable of efficient multi-band operation, making it suitable for high-frequency 5G applications.

 

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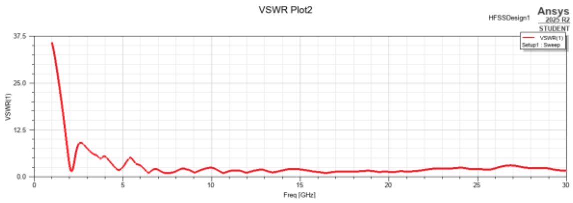


Fig3:VSWR Characteristics of the Proposed Multi-Band Microstrip Antenna

The plot presents the Voltage Standing Wave Ratio (VSWR) characteristics of the designed multi-band microstrip antenna across a frequency span of about 2 GHz to 30 GHz. It can be observed that several frequency regions exhibit VSWR values below 2, which confirms effective impedance matching and efficient transmission of power at those resonant points. In contrast, elevated VSWR levels appear at certain frequencies, indicating poor matching and reduced radiation efficiency in non-resonant regions. Overall, the VSWR response confirms that the antenna maintains satisfactory matching performance operating bands, supporting its suitability for multi-band wireless applications.

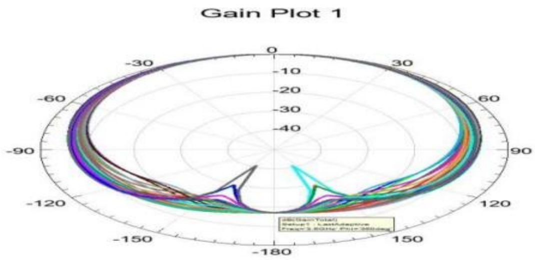


Fig 4:Radiation Gain Pattern of the Proposed Multi-Band Microstrip Antenna

The radiation characteristics of the proposed multi-band microstrip antenna are depicted through thegain pattern obtained from HFSS simulation. The polar representation highlights how the antenna gainvaries with respect to different angular positions, clearly showing its directional behavior. The strongest radiation is concentrated in the broadside direction,which is preferred for efficient wireless communication. Small side lobes and limited back radiation are also present, but their magnitudes are comparatively low. In general, the observed gain distribution indicates consistent and well-controlled radiation performance, confirming the antenna's suitability for 5G wireless applications.

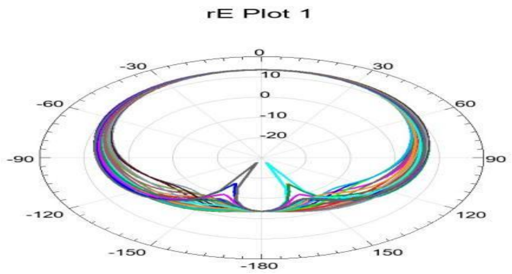


Fig 5:Radiation Efficiency (rE) Pattern of the Proposed Multi-Band Microstrip Antenna

The radiation efficiency (rE) performance of the proposed multi-band microstrip antenna is presented using a polar plot obtained from HFSS simulation. shows how efficiently the antenna radiates power in different angular directions. It can be observed that higher efficiency levels are achieved in the primary radiation region, while a slight reduction is seen in back-lobe directions. Overall, the efficiency distribution indicates that the antenna effectively converts input power into radiated energy, ensuring stable and reliable operation suitable for 5G communication systems.

## CONCLUSION

A multi-band microstrip patch antenna designed for 5G applications has been successfully developed and analyzed. The proposed structure exhibits satisfactory multi-frequency operation with good impedance matching, as confirmed by return loss values below −10 dB and VSWR values less than 2 across the desired frequency bands. In addition, the antenna demonstrates stable radiation characteristics, moderate gain, and efficient power radiation performance. Its compact size, low-profile structure, lightweight nature, and ease of fabrication make it highly suitable for integration into modern wireless communication devices. The obtained results confirm that the designed antenna fulfills the essential requirements for advanced 5G communication systems.

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## FUTURE SCOPE

Further improvements to the antenna design can be achieved by employing advanced techniques such as slot loading, stacking of radiating elements, or incorporation of parasitic structures to enhance bandwidth and gain performance. Reconfigurable designs using components like PIN diodes, varactor diodes, or MEMS switches can be explored to achieve frequency agility and pattern reconfiguration for adaptive 5G environments. The use of low-loss or flexible substrate materials may further enhance efficiency and enable applications in wearable and conformal devices. Moreover, the antenna can be extended into MIMO configurations to improve channel capacity, data rate, and reliability in wireless systems. Future research may also focus on integrating the design with millimeter-wave bands and compact antenna arrays to support emerging beyond-5G and 6G communication technologie

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