Design of Advanced T slot DGS Microstrip patch Antenna for 5G Communication

Bimal Raj Dutta
Electronics & Communication Department. Chandigarh University
Mohali,India
brajdutta@gmail.com

B .A. Santhosh Kumar
Electronics & Communication Department. Chandigarh University
Mohali,India
bangolesanthosh@gmail.com

Vivek Balagani
Electronics & Communication Department. Chandigarh University
Mohali,India
vivekbalagani22@gmail.com

Divyansh Marwaha
Electronics & Communication Department. Chandigarh University
Mohali,India
divyanshm1511@gmail.com

Abstract: The study presents the design of a unique dual-band microstrip patch antenna with a defective ground plane and a T-slot modification on the antenna patch. By increasing bandwidth and improving radiation qualities, the suggested antenna design seeks to attain improved performance characteristics that are appropriate for contemporary wireless communication applications. In proposed work, we used a microstrip patch antenna of dual band frequencies at 27GHz and 38GHz resonance rate at millimeter waves to build a 5G application. FR4 substrate with dielectric constant of 4.3, a rectangular microstrip patch antenna has been designed. With meticulous patch parameter tuning and the addition of a T-slot structure, it displays good gain and VSWR of 1.1 and 1.2, good return loss at 11.605dB, and directivity of 19.8dB. Furthermore, the use of a defective ground plane modifies the electromagnetic field distribution to improve antenna performance even further. In comparison to traditional microstrip patch antennas, modeling findings utilizing CST Micro Studio simulation software show notable improvements in characteristics including return loss, bandwidth, and radiation patterns. The proposed antenna represents a significant advancement in the field of antenna engineering since it provides a viable option for small- and high-performing dual-band wireless communication systems. The aforementioned features attained by this design render the antenna very appropriate for incorporation into 5G communication networks.

***Keywords—* Microstrip patch, Defective ground, T slot, 5G band, Microstrip antenna, Dual band, Band width.**

Introduction

The increasing demands of wireless communication systems for compact, efficient, and versatile antenna solutions have fueled research in this area [1]. Microstrip patch antennas, known for their thin and compact construction, and ease of Incorporating with the modern electronics, have become popular candidates [2]. However, conventional microstrip patch designs often fall short in meeting the requirements of emerging dual-band applications, which necessitate simultaneous operation across multiple frequency bands [3].

In light of these limitations in conventional microstrip patch antenna designs for dual-band applications, this work introduces a novel strategy to achieve enhanced performance characteristics, specifically focusing on wider bandwidth and improved radiation properties. The design incorporates a T-slot modification on a defective ground plane. This configuration (T-slot with defective ground plane) achieves dual-band operation while maintaining a compact form factor. The strategically positioned T-slot on the patch element allows for precise control over resonant frequencies and bandwidths, enabling efficient operation in desired frequency bands [4].

Furthermore, the defective ground plane introduces additional degrees of freedom for manipulating the electromagnetic field distribution. This manipulation leads to enhanced antenna performance characteristics such as radiation efficiency and impedance matching [5]. The effectiveness of the proposed design in achieving dual-band operation with improved performance metrics will be validated through comprehensive electromagnetic simulation and experimental measurements.

Literature

The evolution of wireless communication and mobile handsets has been characterized by significant advancements in technology, leading to increased data rates, improved coverage, and enhanced reliability. As described by various researchers, the allocation of new frequency bands, particularly for 5G communication, has played a crucial role in meeting the growing demands for higher data rates and lower latency.

Kiran et al.[6] highlighted the need for miniature antennas in modern wireless communication systems, emphasizing the benefits of microstrip antennas due to their compact size, low cost, and compatibility with planar circuits. Similarly, Cheekatla et al.[7] discussed the transition from 4G to 5G communication, focusing on the higher data requirements of upcoming technologies and the utilization of millimeter-wave frequencies in 5G communication to address these challenges.

Patch antennas emerged as a promising solution to meet the demands of 5G communication, as demonstrated by Ramli et al.[8] and Yon et al.[9] The benefits and demerits of 5G communication, along with industry standards for certain countries, were highlighted, underscoring the importance of efficient antenna designs in enabling seamless connectivity.

Researchers such as Abedin et al.[10] and Al-Kharusi et al.[11] delved into the structure and functioning of mobile communication systems, detailing the different types of patch antennas and their radiation patterns. Additionally, the

composition and structure of patch antennas, including factors such as air gaps within the substrate, were explored to improve performance metrics such as gain and bandwidth.
The need for small, low-cost, and broad-bandwidth antennas in modern electronics and mobile communications was emphasized by Kumar et al[12]. and Bhunia.[13] Patch antennas were identified as ideal candidates for meeting these specifications, albeit with restrictions on dimensions and materials.
Ojaroudiparchin et al.[14] and Palanivel Rajan et al.[15] discussed the improvements brought by 5G communication and the challenges faced by 5G antennas, such as lower costs, smaller dimensions, and higher gain requirements. The popularity of patch antennas and methods to address their disadvantages were also highlighted.
Various researchers presented their designs for patch antennas, detailing their structure, modes of excitation, fabrication processes, and simulation results. These designs aimed to meet the requirements of modern wireless communication systems, such as improved efficiency, reduced size, and compatibility with multiple frequency bands.[18]-[20].

Proposed Design

Designing the microstrip patch antenna began with the selection of suitable materials. Given the widespread availability and favourable electrical properties, FR4 substrate was chosen, characterized by a relative permittivity (ε_r) of 4.3. This substrate offers a balance of performance, cost-effectiveness, and ease of fabrication.

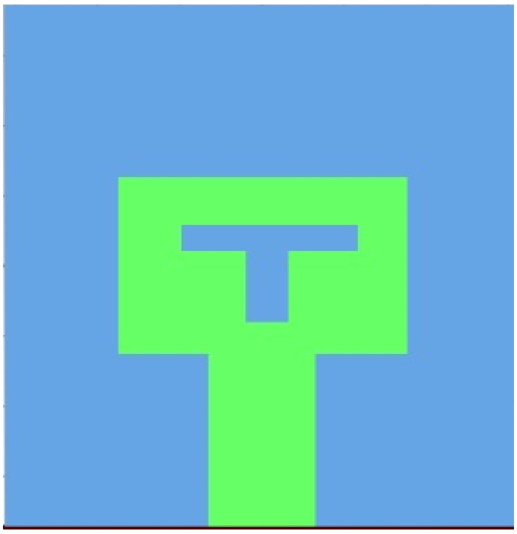

Fig.1Proposed patch design

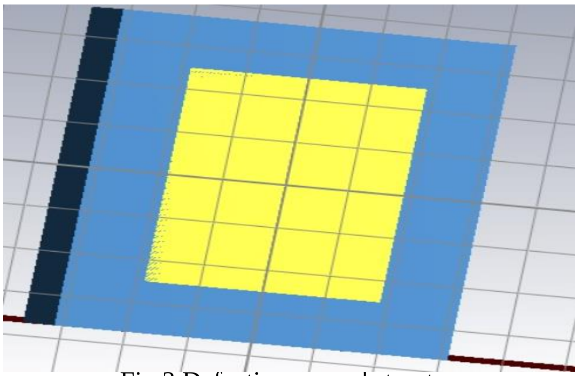

Fig.2 Defective ground structure

The choice of a rectangular patch configuration was made due to its inherent flexibility for accommodating multiple frequency operations. Rectangular patches have demonstrated versatility and effectiveness in various applications, making them a preferred choice for antenna designers.
To optimize the antenna's performance in terms of return loss and bandwidth, modifications were implemented. The key focus was on augmenting crucial design parameters such as the width and length of the substrate. By carefully adjusting these parameters, the resonant frequencies of the antenna could be tuned to desired values, enabling dual-band operation.
Additionally, the introduction of a T-slot modification on the patch element was incorporated to further enhance the antenna's performance. This modification allows for precise control over the distribution of electromagnetic fields, leading to improved impedance matching and radiation characteristics.
The design process utilized the Computer Simulation Technology Microwave Suite (CST Microwave Suite) for electromagnetic simulation and analysis. This software platform provided a comprehensive environment for modelling and optimizing the antenna design. Through iterative simulations and parameter adjustments, the final antenna configuration was achieved, demonstrating improved return loss and enhanced bandwidth compared to conventional designs which are demonstrated at the past.
Overall, the design process involved a systematic approach of modifying key parameters and leveraging advanced simulation tools to achieve the desired performance goals. The resulting microstrip patch antenna offers dual-band operation with enhanced return loss and bandwidth, making it suitable for a wide range of wireless communication applications.

Specifications of proposed antenna

The proposed microstrip patch antenna design incorporates innovative features, including a T-slot modification and a defective ground plane, to enhance its performance characteristics.

T-Slot Modification:

The T-slot modification introduces a slot in the patch element, strategically positioned to alter the electromagnetic field distribution. This modification allows for precise tuning of resonant frequencies and bandwidths, enabling the antenna to achieve dual-band operation at 27 GHz and 38 GHz. By adjusting the dimensions and placement of the T-slot, the antenna's impedance matching and radiation properties can be optimized, leading to improved overall performance.

Defective Ground Plane:

The defective ground plane refers to intentional disruptions or irregularities introduced into the ground plane beneath the antenna structure. These disruptions alter the propagation of electromagnetic waves and the distribution of currents, influencing the antenna's radiation pattern and impedance characteristics [21]-[22]. By carefully engineering the defective ground plane, it is possible to enhance the antenna's bandwidth, gain, and efficiency. Additionally, the defective ground plane can help mitigate surface wave effects and reduce mutual coupling between antenna elements in array configurations.

By combining the T-slot modification with the implementation of a defective ground plane, the proposed antenna design achieves synergistic improvements in performance. The T-slot allows for fine-tuning of frequency response, while the defective ground plane optimizes radiation properties and mitigates unwanted effects. Through comprehensive simulation and validation, these innovative design features contribute to the development of a compact, efficient, and versatile microstrip patch antenna suitable for a wide range of wireless communication applications.

Parameter Analysis:

The most optimal conditions and combination are found to design this patch antenna are given in the parameter analysis for the microstrip patch antenna, specific attention was given to achieving dual-band operation at frequencies of 27 GHz and 38 GHz. The optimization process involved tuning key design parameters, including substrate dimensions, patch geometry, and slot dimensions, to ensure resonance at both target frequencies. By systematically varying these parameters and simulating the antenna's performance using CST Microwave Suite, optimal configurations were identified to achieve resonance and impedance matching at 27 GHz and 38 GHz. Furthermore, the choice of FR4 substrate with a relative permittivity (ε_r) of 4.3 was critical in facilitating dual-band operation while maintaining compactness and cost-effectiveness. Through rigorous analysis, the parameter optimization

Parameter Symbols	Details of the Parameters	Value in (mm)
W_S	Width of substrate	7.4
L_S	Length of substrate	6.25
W	Width of patch	2.5
L	Length of patch	3.5
W_F	Width of feed	0.3
L_F	Length of feed	1.3
H	Height of the substrate	0.035

Tabel:1 parameters of the proposed design

The patch required to design the suggested antenna can be found using the following formulae[23]-[24].

$$W = \frac{C}{2f_r}\sqrt{\frac{2}{\epsilon_r+1}} \qquad (1)$$

Where C is light speed, f_r is Frequency and ϵ_r is Constant of Dielectric

$$L = L_{eff} - \Delta L \qquad (2)$$

Here, the patch's effective length must be determined in the manner described below in order to determine its length.

$$L_{eff} = \frac{C}{2f_r\sqrt{\epsilon_{eff}}} \qquad (3)$$

As mentioned below, ϵ_{eff} represents the effective dielectric constants.

$$\epsilon_{eff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left(1+\frac{10h}{w}\right) \qquad (4)$$

Now, let's look at the extension length ΔL:

$$\Delta L = 0.412h\frac{(\epsilon_r+0.3)\left(\frac{w}{h}+0.264\right)}{(\epsilon_r+0.258)\left(\frac{w}{h}+0.8\right)} \qquad (5)$$

Simulation on CST Microwave suit:

The parameters listed in the above Table serve as the foundation for designing our antenna within the Computer Simulation Technology Microwave Suite (CST Microwave Suite). Utilizing these parameters, we input the necessary dimensions and specifications into the CST software, to visualize the finalized antenna design. Following the completion of the design process in CST software, simulations are conducted to analyze various antenna performance metrics, including VSWR, S-parameters, and other mathematical values. These results provide crucial insights into the antenna's behavior and performance characteristics, guiding further refinements and optimizations to meet our project objectives.

Results Analysis.

A. Coefficient of reflection:

The S11 parameter, often referred to as the reflection coefficient, characterizes the loss of return at the input and output ports of an antenna, indicating the amount of power that is radiated from the antenna. The return loss plot illustrates the degree of impedance matching between the feedline and the antenna. A low return loss coefficient, typically aiming for -10 dB, signifies efficient antenna performance by reflecting the ratio of incident power to radiated power. The proposed design has got the best result - as per our expectation of -11dB

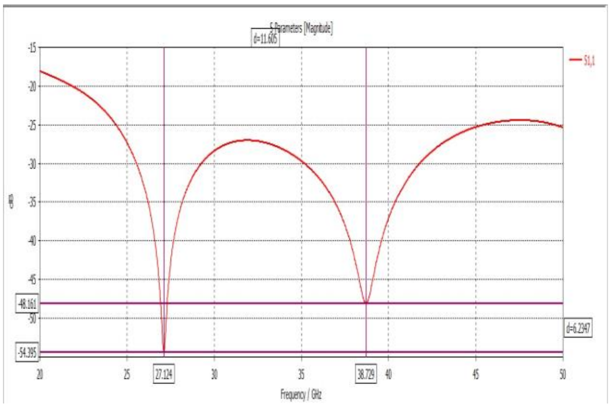

Fig.3 loss return graph

For the dual-band microstrip patch antenna operating at 27 GHz and 38 GHz, the S-parameters were analyzed across the frequency range of interest. The S11 parameter, also known as the return loss, indicates the amount of power reflected back from the antenna due to impedance mismatch. A lower S11 value corresponds to better impedance matching and reduced reflection loss.

B. VSWR

The Voltage Standing Wave Ratio (VSWR) is a critical parameter that characterizes the impedance matching and reflection properties of an antenna. The ratio must lie between 0 and 1 which is consider as a good parameter for an antenna. The values of the of the VSWR is always positive.[28] Our antenna with the above discussions it has a worth of 1.1 and 1.2 respectively

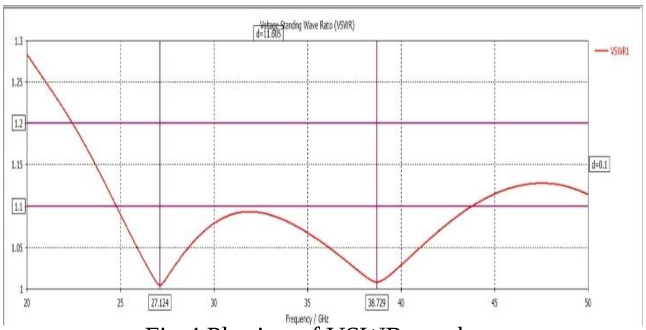

Fig.4 Plotting of VSWR graph

A VSWR value close to 1 signifies nearly perfect impedance matching, resulting in efficient power transfer from the transmission line to the antenna, and subsequently, to free space. The obtained VSWR values validate the effectiveness of the proposed antenna design in achieving dual-band operation with optimized impedance matching characteristics.

C. Radiation pattern

The antenna radiation pattern visually represents the energy radiated by the antenna [26]-[27] both the 3D and 2D radiation patterns illustrate a high gain of 16.7 dB.

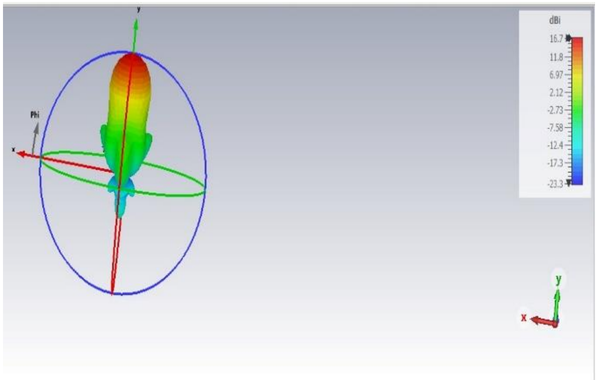

Fig.5 3D pattern of gain

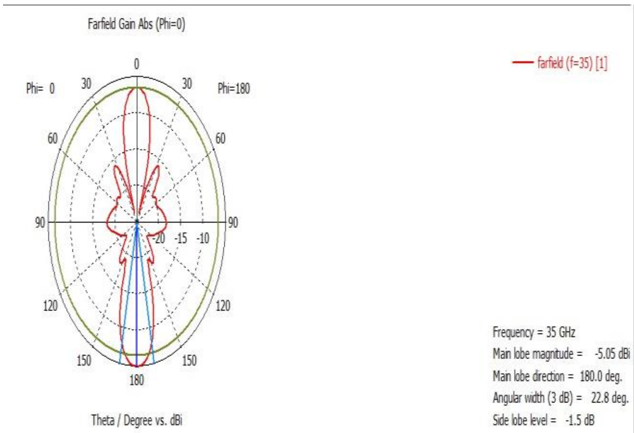

Fig.6 2D at 35GHz when phi=0

Directivity

Directivity measures an antenna's ability to focus radiation in a specific direction compared to an isotropic radiator. It quantifies the concentration of radiated power in a desired direction. Higher directivity signifies more focused radiation, leading to increased signal strength and improved communication performance. Antenna design and geometry influence directivity, with directional elements or arrays used to enhance it. In our case the peak value of directivity of the proposed design is 19.8dB

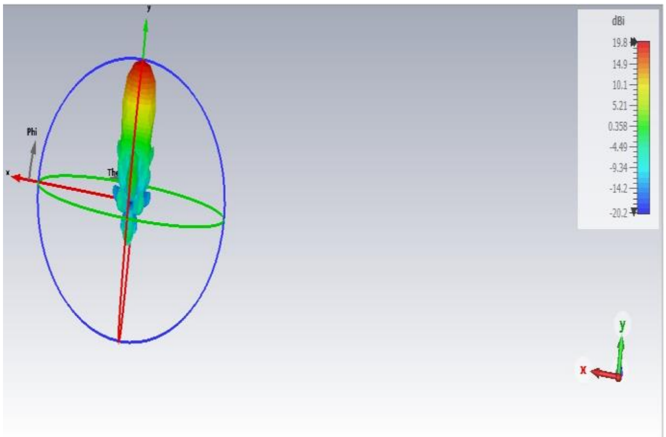

Fig.7 3D pattern of directivity

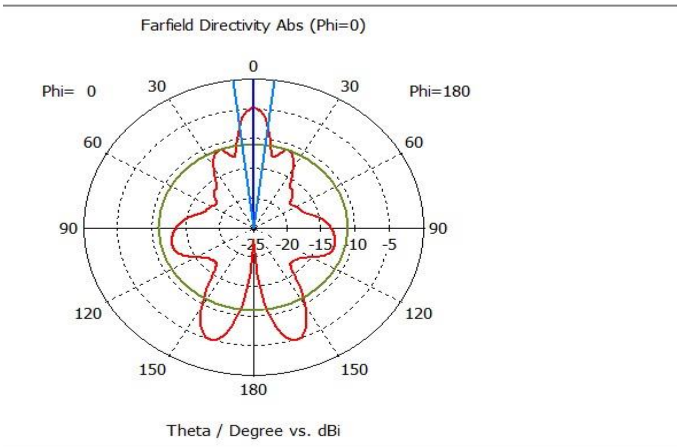

Fig.8 2D pattern at 50GHz when phi=0

Patch antennas for 5G in comparison to the microstrips to our microstrip patch antenna.

References	Resonance Frequencies	Return loss in dB	Gain in dB	Bandwidth in GHz	VSWR
[23]	39 GHz	-31.02	4	3.5	1.04
[27]	28 GHz	-18.25	6.83	1.1	1.2
[28]	2.5 GHz & 3.5 GHz	-10dB	7.8	3	1.4
Proposed Design	27GHz & 38GHz	-11.605	16.7	5.4	1.1 &1.2

Tabel:2 comparison of proposed design with other designs

Conclusion

the design and optimization of dual-band microstrip patch antennas with innovative features such as T-slot modification and defective ground planes offer significant advancements in modern wireless communication systems. Through comprehensive simulation and experimental, the proposed antenna design demonstrates efficient dual-band operation, low VSWR values, and high directivity, meeting the demands of emerging technologies like 5G communication. The extensive literature review underscores the importance of efficient antenna designs in enabling seamless connectivity and highlights the potential of patch antennas in addressing the challenges of modern wireless communication. Moving forward, continued research and development in antenna engineering will play a pivotal role in advancing the capabilities of wireless communication systems, ensuring enhanced performance, reliability, and connectivity for diverse applications.

Future work

In the above proposed design, several avenues present themselves for further exploration and refinement of dual-band microstrip patch antennas with T-slot modification and defective ground planes. And these are not only the way here implemented it. There are many ways like integrating other than T slot as per their requirement but first, there is a need to optimize the antenna design to meet the specific requirements of various applications, such as IoT devices, satellite communication, or vehicular communication systems. Tailoring the design accordingly can enhance its effectiveness and versatility in diverse scenarios. Second, efforts can be directed towards miniaturization and integration, investigating methods to shrink the antenna's size while maintaining or improving its performance characteristics to enable integration into smaller form factors and compact devices. Additionally, exploring techniques to enhance the antenna's bandwidth to support additional frequency bands or wider frequency ranges is essential to accommodate evolving communication standards and spectrum allocations. Durability and reliability studies are also warranted to assess the antenna's performance under harsh environmental conditions, ensuring its suitability for real-world deployment. Moreover, investigating the potential benefits of array configurations of dual-band microstrip patch antennas, including phased arrays or MIMO systems, could lead to improved spatial diversity, beamforming, and interference mitigation. Advanced fabrication methods, such as additive manufacturing or flexible electronics, should also be explored to streamline the manufacturing process and enable rapid prototyping of customized antenna designs. Lastly, exploring opportunities for synergy with emerging technologies such as artificial intelligence, machine learning, or metamaterials can further optimize antenna performance and unlock new capabilities. By embarking on these avenues of future work, researchers can continue to push the boundaries of antenna engineering, unlocking new possibilities for enhanced performance, reliability, and connectivity in modern wireless communication systems.

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