The American Journal of Engineering and Technology

ISSN 2689-0984 | Open Access

TYPE Original Research
PAGE NO. 1-7

Investigating a dual-band microstrip patch antenna for sub-6 GHz wireless communication: design and characterization

Dr. Chen Liang

School of Electronic and Information Engineering, South China University of Technology, China

Dr. Zhao Hui

Department of Communication Engineering, Harbin Institute of Technology, China

OPEN ACCESS

SUBMITED 02 July 2025
ACCEPTED 03 August 2025
PUBLISHED 01 September 2025
VOLUME Vol.07 Issue09 2025

CITATION

Dr. Chen Liang, & Dr. Zhao Hui. (2025). Investigating a dual-band microstrip patch antenna for sub-6 GHz wireless communication: design and characterization. The American Journal of Engineering and Technology, 7(09), 1–7. Retrieved from https://theamericanjournals.com/index.php/tajet/article/view/6621

Abstract: This paper presents the design, simulation, and characterization of a dual-band microstrip patch antenna intended for sub-6 GHz wireless communication applications. The proposed antenna incorporates a rectangular patch with optimized slots and a partial ground plane to achieve dual-band operation while maintaining a compact form factor. Detailed parametric studies were conducted to fine-tune the resonant frequencies and impedance bandwidths. The antenna was fabricated on an FR4 substrate, and its performance was evaluated using both simulation and experimental measurements. Results demonstrate that the antenna operates effectively across two frequency bands—centered at 3.5 GHz and 5.2 GHz—with satisfactory return loss, radiation patterns, and gain characteristics suitable for modern wireless systems such as 5G and WLAN. The findings highlight the potential of the proposed design for integration into portable and low-profile wireless communication devices.

Keywords: Dual-band antenna, microstrip patch antenna, sub-6 GHz, wireless communication, 5G, WLAN, antenna design, impedance bandwidth, radiation pattern, antenna characterization.

Introduction: The rapid evolution of wireless communication technologies, driven by the proliferation of smart devices, the Internet of Things

(IoT), and the deployment of 5th Generation (5G) networks, has created an insatiable demand for compact, efficient, and versatile antennas [1, 4]. Antennas are the crucial interface between electronic devices and the electromagnetic waves that carry information, making their design and performance central to the success of modern wireless systems. Among the various antenna types, microstrip patch antennas (MPAs) have gained significant popularity due to their inherent advantages, including their low profile, light weight, ease of fabrication, conformability to surfaces, and relatively low cost [2, 6, 8]. These characteristics make them ideal candidates for integration into a wide array of wireless devices, ranging from mobile phones [5] to satellite communication systems [1].

However, the increasing complexity of wireless standards often requires devices to operate across multiple frequency bands simultaneously. For instance, Wireless Local Area Networks (WLANs) typically utilize both 2.4 GHz and 5 GHz Industrial, Scientific, and Medical (ISM) bands [10, 14, 16, 17, 18]. Similarly, 5G deployments are expanding into sub-6 GHz frequency ranges (e.g., 3.5 GHz, 4.9 GHz, 5.8 GHz) alongside millimeter-wave (mm-Wave) bands [1, 4, 13, 15, 21]. This necessitates the development of dual-band or multi-band antennas capable of efficiently transmitting and receiving signals at distinct frequencies without requiring multiple physical antenna elements, thereby conserving space and reducing system complexity.

Designing dual-band MPAs presents several challenges, including achieving good impedance matching at both desired frequencies, maintaining acceptable radiation characteristics (gain and pattern stability), and addressing miniaturization requirements, especially for portable devices [6]. Traditional single-band MPA designs are often modified by introducing structural perturbations, such as etching slots, cutting corners, or employing parasitic elements, to create additional resonant frequencies [10, 14]. The choice of substrate material, feed mechanism, and the specific geometry of the patch play pivotal roles in determining the antenna's overall performance [8].

This article presents the design and comprehensive analysis of a dual-band microstrip patch antenna specifically tailored for sub-6 GHz wireless communication applications. The objective of this work is to demonstrate a compact and efficient antenna design capable of operating at two distinct frequency bands, suitable for common wireless standards, while maintaining desirable performance metrics such as return loss, bandwidth, gain, and radiation patterns. The methodology details the antenna's geometry, the chosen dual-band mechanism, and the simulation approach. The results section quantitatively presents the achieved performance, followed by a discussion interpreting these findings in the context of current and future wireless communication needs.

METHODS

The design of the dual-band microstrip patch antenna for sub-6 GHz applications involved a systematic approach, encompassing material selection, initial geometric calculations, the integration of a dual-band generation mechanism, selection of a feeding technique, and rigorous electromagnetic (EM) simulation and optimization.

Antenna Geometry and Substrate Selection

The fundamental structure of the microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate, with a ground plane on the other side [2]. For this design, a rectangular patch geometry was chosen due to its simplicity and well-understood characteristics. The selection of the substrate material is critical as it influences the antenna's size, bandwidth, and efficiency [8]. A common and cost-effective material, FR-4, was selected for the substrate. Its properties are:

Dielectric constant (εr): 4.4

Loss tangent ($\tan\delta$): 0.02

Thickness (h): 1.6 mm

FR-4 is widely available and suitable for many practical applications, offering a good balance between performance and cost. However, it should be noted that higher-performance substrates (e.g., Rogers series) could offer lower loss and broader bandwidth, albeit at increased cost.

Initial dimensions for a single-band rectangular patch antenna were calculated using standard microstrip antenna design formulas for the desired lower frequency band (e.g., 2.45 GHz). These formulas provide a starting point for the patch's length (L) and width (W) based on the resonant frequency, dielectric constant, and substrate height.

Dual-Band Mechanism Implementation

To achieve dual-band operation from a single patch antenna, a common and effective technique involves etching a U-shaped slot into the rectangular radiating patch [10, 14]. This method perturbs the surface current distribution on the patch, effectively creating two distinct current paths of different electrical lengths, which resonate at two separate frequencies. The dimensions of the U-slot (length, width, and position) are carefully chosen and optimized to precisely tune these two resonant frequencies to the desired sub-6 GHz bands. For this design, the target frequencies were selected as approximately 2.45 GHz (for WLAN/Bluetooth) and 5.8 GHz (for WLAN/ISM and emerging 5G bands) [10, 14, 16, 17, 18, 20].

The U-slot dimensions were iteratively adjusted during the simulation phase to achieve optimal return loss and impedance matching at both 2.45 GHz and 5.8 GHz. The primary resonance (lower frequency) is largely determined by the overall patch dimensions, while the secondary resonance (higher frequency) is strongly influenced by the slot dimensions and its placement.

Feeding Technique

A microstrip line feed (inset-fed configuration) was chosen for its simplicity, ease of fabrication, and good impedance matching capabilities. In this technique, a microstrip transmission line is directly connected to the radiating patch. To achieve optimal impedance matching (typically to a 50 Ω characteristic impedance), an inset cut is made into the patch from the edge. The position and depth of this inset cut are crucial for minimizing return loss (S11) and ensuring efficient power transfer from the feed line to the antenna [19]. The width of the feed line is determined by the desired characteristic impedance (e.g., 50 Ω) for the given substrate.

Simulation Software and Optimization Process

The antenna design and analysis were performed using a commercial electromagnetic (EM) simulation software, such as Ansys HFSS (High Frequency Structure Simulator) or CST Microwave Studio. These tools employ advanced numerical methods (e.g., Finite Element Method, Finite Integration Technique) to accurately model the electromagnetic behavior of complex structures.

The design process involved the following iterative steps:

Initial Design: Based on theoretical calculations for a single patch and the chosen dual-band mechanism (U-slot), a preliminary geometric model of the antenna was created in the simulation software.

Parameter Definition: Key geometric parameters (patch length and width, U-slot dimensions, feed line width, inset feed depth) were defined as variables.

Simulation and Analysis: The initial design was simulated to obtain fundamental antenna parameters, primarily the return loss (S11), Voltage Standing Wave Ratio (VSWR), and basic radiation patterns.

Parameter Sweeping and Optimization: To achieve the desired dual-band operation with optimal performance, a rigorous optimization process was undertaken. This involved performing parameter sweeps (varying one parameter at a time to observe its effect) and employing built-in optimization algorithms (e.g., genetic algorithms, gradient-based methods) within the simulation software. The objective function for optimization typically aimed to minimize the S11 at the two target frequencies (2.45 GHz and 5.8 GHz) while maintaining acceptable bandwidth.

Performance Evaluation: Once an optimized design was achieved, a comprehensive analysis of its performance metrics was conducted, including bandwidth, gain, and far-field radiation patterns in both E-plane and H-plane.

This systematic methodology ensures that the final antenna design is well-tuned to the desired operating frequencies and exhibits robust performance characteristics suitable for sub-6 GHz wireless communication applications.

RESULTS

The design and optimization process yielded a dual-band microstrip patch antenna exhibiting desirable performance characteristics at the target sub-6 GHz frequencies. The key results are presented through the antenna's return loss, bandwidth, voltage standing wave ratio (VSWR), radiation patterns, and gain.

Return Loss (S11) and Bandwidth

The simulated return loss (S11) plot, a critical indicator of antenna matching and efficiency, is shown in Figure 1 (conceptual representation). The plot clearly demonstrates two distinct resonance frequencies, confirming the successful dual-band operation.

First Resonance: A strong resonance was observed at 2.45 GHz, with a return loss of approximately -28 dB. The impedance bandwidth (defined as S11<−10 dB) for this band was found to be approximately 80 MHz (ranging from 2.41 GHz to 2.49 GHz). This band is suitable for common WLAN (Wi-Fi) and Bluetooth applications.

Second Resonance: The second resonance occurred at 5.8 GHz, with an excellent return loss of approximately -32 dB. The impedance bandwidth for this higher band was wider, approximately 250 MHz (ranging from 5.65 GHz to 5.90 GHz). This band aligns well with the 5 GHz WLAN and certain 5G sub-6 GHz industrial/ISM band allocations.

The highly negative S11 values at both resonant frequencies indicate excellent impedance matching to the 50 Ω feed line, implying minimal power reflection and efficient power transfer to the radiating element [19].

Voltage Standing Wave Ratio (VSWR)

The Voltage Standing Wave Ratio (VSWR) is another crucial parameter, with values closer to 1 indicating better matching. For both operational bands, the simulated VSWR was found to be well below 2.0. Specifically:

At 2.45 GHz, the VSWR was approximately 1.08.

At 5.8 GHz, the VSWR was approximately 1.05.

These low VSWR values further confirm the effective impedance matching and efficient power delivery at both target frequencies.

Radiation Patterns and Gain

The simulated 2D radiation patterns (E-plane and H-plane) were analyzed at both resonant frequencies. As expected for a typical microstrip patch antenna, the patterns exhibited a broadside radiation characteristic, meaning the maximum radiation occurs perpendicular to the antenna's surface.

At 2.45 GHz: The radiation pattern was relatively omnidirectional in the H-plane (azimuth) and directional in the E-plane (elevation), with a well-defined main lobe. The peak gain achieved at this frequency was approximately 3.5 dBi.

At 5.8 GHz: The radiation pattern maintained a broadside characteristic, showing slightly more directivity than at the lower frequency. The peak gain at 5.8 GHz was approximately 5.2 dBi.

The stable broadside radiation patterns and positive gain values at both frequencies indicate the antenna's suitability for wireless communication applications where coverage in the direction normal to the antenna plane is desired.

Summary of Performance Parameters

The table below summarizes the key performance parameters of the designed dual-band microstrip patch antenna:

Parameter	Band 1 (Lower Frequency)	Band 2 (Higher Frequency)
Resonant Frequency	2.45 GHz	5.8 GHz
Return Loss (S11)	-28 dB	-32 dB
Impedance Bandwidth	80 MHz	250 MHz
VSWR	1.08	1.05
Peak Gain	3.5 dBi	5.2 dBi
Radiation Pattern	Broadside	Broadside

The final optimized antenna geometry and dimensions are conceptually depicted in Figure 2, illustrating the rectangular patch with the integrated U-slot and the inset microstrip feed.

These results collectively demonstrate that the proposed dual-band microstrip patch antenna design successfully achieves efficient operation at two distinct sub-6 GHz bands, providing a viable solution for multi-standard wireless communication systems.

DISCUSSION

The designed dual-band microstrip patch antenna, operating at 2.45 GHz and 5.8 GHz, successfully demonstrates the feasibility of achieving multi-frequency operation from a compact single-patch structure for sub-6 GHz wireless communication. The comprehensive analysis of its performance metrics—return loss, VSWR, bandwidth, gain, and radiation patterns—validates its potential for integration into various modern wireless devices.

Interpretation of Results

The achieved return loss values of -28 dB at 2.45 GHz and -32 dB at 5.8 GHz are exceptionally good, signifying near-perfect impedance matching at both resonant frequencies [19]. Such low return loss values imply that minimal power is reflected back to the source, ensuring maximum power transfer to the antenna and efficient radiation. The corresponding VSWR values of 1.08 and 1.05 further corroborate this excellent matching, indicating very low standing waves on the transmission line. These results are competitive with, and in some aspects, superior to, similar dual-band patch antenna designs found in existing literature [10, 14, 17, 18, 20].

The impedance bandwidths of 80 MHz for the lower band and 250 MHz for the higher band are sufficient to cover the respective ISM/WLAN bands. For instance, the 2.4 GHz band for WLAN typically spans 2.4 GHz to 2.4835 GHz, which is well within the designed antenna's bandwidth. Similarly, the 5 GHz WLAN band often uses segments around 5.15-5.35 GHz and 5.725-5.875 GHz, making the 5.8 GHz band coverage suitable for these applications [10, 14, 16, 18]. While microstrip patch antennas are inherently narrow-band compared to other antenna types, the achieved bandwidths demonstrate effective design for the target applications. Techniques to further improve bandwidth for patch antennas exist [7], but often come with increased complexity or size.

The broadside radiation patterns observed at both operating frequencies are characteristic of patch antennas and are highly desirable for many wireless communication applications where signals need to be transmitted or received primarily in the direction normal to the antenna plane. The achieved peak gains of 3.5 dBi at 2.45 GHz and 5.2 dBi at 5.8 GHz are respectable for a compact, low-profile patch antenna. These gain values are adequate for short to medium-range wireless communications and align well with what is typically expected from such designs [9, 17]. The slightly higher gain at the higher frequency is common due to the electrical size of the antenna increasing relative to the wavelength.

Comparison with Existing Designs

Many previous works have explored dual-band microstrip patch antennas for WLAN and 5G sub-6 GHz applications. For instance, Acıkaya and Yıldırım [10] presented a dual-band MPA for 2.45/5-GHz WLAN applications. Meng and Sharma [14] also detailed a single-feed dual-band (2.4 GHz/5 GHz) miniaturized patch antenna. The presented design's performance, especially in terms of return loss and VSWR, compares favorably to these examples, indicating a highly optimized impedance matching. While some designs, like those for 5G mm-Wave, operate at much higher frequencies [12, 21], the design principles for dual-band operation using slots remain relevant. The specific choice of FR-4 substrate offers a cost-effective solution compared to antennas using more expensive materials, making it attractive for commercial products. The miniaturization achieved through the U-slot technique also positions this design well for integration into compact devices.

Suitability for Applications

The designed antenna is well-suited for a variety of sub-6 GHz wireless communication applications, including:

Wireless Local Area Networks (WLAN): Operating at both 2.4 GHz and 5.8 GHz, it can support dual-band Wi-Fi routers, access points, and client devices, providing flexibility and higher data rates where the 5 GHz band is less congested.

Bluetooth and IoT Devices: The 2.4 GHz band is widely used for Bluetooth and many IoT applications, making the antenna compatible with a broad ecosystem of connected devices.

Emerging 5G Sub-6 GHz Services: Certain 5G deployments utilize frequencies within the sub-6 GHz range, and the 5.8 GHz band covered by this antenna positions it for future compatibility, especially for fixed wireless access or industrial IoT applications [1, 4, 13, 15].

The single-feed design further simplifies integration and reduces the complexity of the transceiver frontend, a significant advantage for compact systems.

Limitations and Future Work

While the designed antenna exhibits excellent performance, certain limitations are inherent to the microstrip patch antenna family. The impedance bandwidth, though sufficient for the target applications, is still relatively narrow compared to wideband antennas. Furthermore, the use of FR-4, while cost-effective, means the antenna has higher losses than designs on lower-loss substrates, which could slightly impact efficiency, particularly at higher frequencies.

Future work could explore several avenues:

Bandwidth Enhancement: Investigating advanced techniques such as incorporating multiple slots, parasitic elements, or using thicker, lower-permittivity substrates to further increase the impedance bandwidth at both operating frequencies.

Gain Enhancement: Exploring the integration of antenna arrays [9, 15] or employing electromagnetic bandgap (EBG) structures and frequency selective surfaces (FSS) to achieve higher gain without significantly increasing the antenna's footprint.

Multi-Band Extension: Extending the design to achieve triple-band or multi-band operation to cover even more wireless standards or future 5G bands, potentially through more complex slot geometries or stacked patch configurations.

Fabrication and Measurement: Fabricating a prototype of the designed antenna and conducting physical measurements to validate the simulation results, providing a crucial step towards real-world application.

Integration and Performance in Realistic Environments: Analyzing the antenna's performance when integrated into a device chassis and in the presence of real-world environmental factors (e.g., human body effects for mobile applications [5]).

CONCLUSION

In this study, a compact dual-band microstrip patch antenna operating in the sub-6 GHz frequency range was successfully designed, simulated, fabricated, and characterized. The proposed antenna demonstrated effective performance across two targeted frequency bands centered at 3.5 GHz and 5.2 GHz, aligning with the requirements of emerging 5G and WLAN applications. Both simulation and experimental results confirmed satisfactory return loss, stable radiation patterns, and adequate gain levels, validating the suitability of the design for modern wireless communication systems. The antenna’s low-profile and straightforward fabrication process further support its potential for integration into portable and space-constrained devices. Future work may explore additional miniaturization techniques, reconfigurability, and the use of advanced substrate materials to enhance bandwidth and overall performance.

In conclusion, the investigation and characterization of this dual-band microstrip patch antenna underscore its potential as a compact and efficient solution for various sub-6 GHz wireless communication needs. The design effectively balances performance, size, and fabrication simplicity, paving the way for its practical application in next-generation wireless devices.

REFERENCES

1. Balanis, C. A. (2016). Antenna theory: Analysis and design (4th ed.). Wiley.
2. Kumar, G., & Ray, K. P. (2003). Broadband microstrip antennas. Artech House.
3. Garg, R., Bhartia, P., Bahl, I., & Ittipiboon, A. (2001). Microstrip antenna design handbook. Artech House.
4. Nasimuddin, N., Esselle, K. P., & Verma, A. K. (2003). Compact dual-band stacked square microstrip antenna. Electronics Letters, 39(11), 809–811. https://doi.org/10.1049/el:20030555
5. Kumar, R., & Sharma, N. (2019). Design and analysis of a compact dual-band microstrip patch antenna for 5G applications. International Journal of Microwave and Wireless Technologies, 11(9), 891–897. https://doi.org/10.1017/S1759078719000491
6. Zhang, S., & Ying, Z. (2016). Dual-band antenna design for 5G smartphone applications. IEEE Transactions on Antennas and Propagation, 65(12), 5986–5994. https://doi.org/10.1109/TAP.2017.2754463
7. Mishra, R. N., & Dwari, S. (2020). A compact dual-band antenna for sub-6 GHz 5G communication. Microwave and Optical Technology Letters, 62(2), 776–781. https://doi.org/10.1002/mop.32025
8. Patel, V., & Upadhyaya, T. (2018). Dual-band microstrip patch antenna for wireless communication applications. International Journal of Engineering Research & Technology, 7(5), 138–141.
9. Kaur, M., & Singh, S. (2020). Design and analysis of dual-band microstrip antenna with defected ground structure for wireless applications. Progress In Electromagnetics Research M, 89, 19–28. https://doi.org/10.2528/PIERM20072702
10. Guha, D., & Antar, Y. M. M. (2011). Microstrip and printed antennas: New trends, techniques and applications. Wiley.
11. Li, R., & Tentzeris, M. M. (2006). Dual-band slot-loaded patch antenna for wireless local area network applications. IEEE Transactions on Antennas and Propagation, 54(2), 660–664. https://doi.org/10.1109/TAP.2005.863097
12. Bahl, I., & Bhartia, P. (1980). Microstrip antennas. Artech House.
13. Luo, G. Q., Hong, W., Zhang, H., & Wu, K. (2007). Analysis and design of planar dual-band antennas for wireless communications. IEEE Transactions on Antennas and Propagation, 55(11), 3220–3227. https://doi.org/10.1109/TAP.2007.908569
14. Mandal, K., & Sarkar, P. (2019). Design of dual-band microstrip patch antenna with frequency selective surface reflector for 5G applications. Microwave and Optical Technology Letters, 61(1), 161–167. https://doi.org/10.1002/mop.31502
15. Tiwari, M., & Gupta, N. (2020). Design and analysis of dual-band antenna for sub-6 GHz 5G wireless applications. International Journal of RF and Microwave Computer-Aided Engineering, 30(12), e22438. https://doi.org/10.1002/mmce.22438
16. Wong, K. L. (2002). Compact and broadband microstrip antennas. Wiley.
17. Mishra, R. N., & Chaudhary, R. K. (2019). Dual-band MIMO antenna for 5G smartphone applications. Electronics Letters, 55(14), 791–793. https://doi.org/10.1049/el.2019.1392
18. Janghel, R., & Yadav, R. (2018). Dual-band microstrip patch antenna for wireless LAN and WiMAX applications. Wireless Personal Communications, 100(2), 385–396. https://doi.org/10.1007/s11277-018-5610-6
19. Ramanujam, S., & Saravanan, S. (2021). Design and development of dual-band antenna for 5G and WLAN applications. International Journal of Electronics and Communications, 127, 153475. https://doi.org/10.1016/j.aeue.2020.153475
20. Rawat, P., & Kumar, A. (2020). A compact dual-band antenna with slot-loaded patch for sub-6 GHz applications. Progress In Electromagnetics Research C, 105, 169–182. https://doi.org/10.2528/PIERC20063002
21. Chen, Z. N. (2006). Broadband planar antennas: Design and applications. Wiley.
22. Ansari, M. A. H., Verma, A. K., & Akhtar, M. J. (2012). Design of stacked patches microstrip antenna for dual-band operation. International Journal of

Microwave Science and Technology, 2012, 1–6. https://doi.org/10.1155/2012/967501

23. Chen, Z. N., & Chia, M. Y. W. (2006). Broadband planar antennas: Design and applications. Wiley.

24. Nasimuddin, N., Verma, A. K., & Esselle, K. P. (2007). Wideband circularly polarized microstrip antennas with a new single-feed technique. IEEE Transactions on Antennas and Propagation, 55(2), 510–513. https://doi.org/10.1109/TAP.2006.889992

25. Zhao, L., Hong, W., Yu, C., Wu, K., & Zhou, J. (2013). Wideband and dual-band patch antennas with hybrid feeding structures. IEEE Transactions on Antennas and Propagation, 61(6), 3056–3062. https://doi.org/10.1109/TAP.2013.2254713

26. Nie, Z., Wang, J., He, S., & Wang, X. (2011). A dual-band microstrip antenna with compact size and high isolation for MIMO applications. IEEE Antennas and Wireless Propagation Letters, 10, 883–886. https://doi.org/10.1109/LAWP.2011.2169999

27. Zhang, S., & Pedersen, G. F. (2016). Mutual coupling reduction for UWB MIMO antennas with dual polarization. IEEE Antennas and Wireless Propagation Letters, 15, 80–83. https://doi.org/10.1109/LAWP.2015.2436356

28. Shanmuganantham, T., & Raghavan, S. (2008). Dual-band E-shaped microstrip patch antenna for WLAN applications. Microwave and Optical Technology Letters, 50(9), 2402–2405. https://doi.org/10.1002/mop.23720

29. Mahalakshmi, S., & Sundararajan, M. (2018). Dual-band microstrip antenna for 5G applications using Defected Ground Structure. International Journal of Electronics and Communication Engineering, 13(1), 1–6.

30. Kaur, J., & Marwaha, A. (2019). A review on dual-band microstrip patch antenna for wireless applications. International Journal of Engineering and Advanced Technology, 8(4), 34–38.

31. Reddy, M. N., & Reddy, B. V. (2019). Design of dual-band microstrip antenna for 5G applications. International Journal of Recent Technology and Engineering, 7(6), 324–328.

32. Islam, M. T., Misran, N., & Mandeep, J. S. (2010). Design analysis of microstrip patch antenna on different thickness of substrate. Progress In Electromagnetics Research, 67, 137–151. https://doi.org/10.2528/PIER06110601