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Design and Implementation of a Dual-Band Microstrip Patch Antenna for Wireless Bridging at 2.4 GHz and 5.0 GHz

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Abstract

This study presents the design and implementation of a compact dual-band microstrip patch antenna incorporating rectangular-shaped and U-slots for wireless bridging at 2.4 GHz and 5.0 GHz. The antenna was designed and simulated using CST Studio software and fabricated on a low-cost FR-4 substrate with a dielectric relative permittivity constant of 4.3 and a thickness of 1.6 mm, with overall dimensions of 76 x 59 mm^2. Simulation results showed resonant frequencies at 2.4 GHz and 5.0 GHz, with return losses of -15.9 dB and -20.5 dB, and bandwidths of 80 MHz and 180 MHz, respectively. The measured results closely matched the simulation, with return losses of -15.9 dB at 2.4 GHz and -10.0 dB at 5.1 GHz. The antenna exhibited directional radiation patterns and low VSWR below 2.0 in both bands. It was applied in a 20-meter point-to-point wireless bridging system using MikroTik L11UG-5HaxD devices, achieving 120 Mbps at the access point and 74 Mbps at the client. Results confirm the antenna's compact size, efficiency and suitability for reliable Wi-Fi and short-range wireless bridging.

1. Introduction

The rapid growth of wireless communication systems has increased the demand for compact, efficient and multiband antennas. Modern wireless devices such as routers, access points, and wireless bridges commonly operate in the 2.4 GHz and 5.0 GHz bands to comply with IEEE 802.11 standards. Microstrip patch antennas are widely preferred due to their low profile, lightweight structure, low cost, ease of fabrication and planar design [1]-[5]. Single-band antennas that operate only at 2.4 GHz suffer from congestion, interference, and limited flexibility in high-traffic environments. Although dual-band antennas are available, many existing designs are bulky, complex, costly or fail to provide stable performance across both frequency bands [6]-[7]. These limitations create challenges for wireless bridging applications that require directional radiation, reliable gain and stable throughput.

This project aims to design, fabricate and evaluate a compact dual-band U-slot microstrip patch antenna operating at 2.4 GHz and 5.0 GHz for wireless bridging applications. The antenna will be designed and optimised in CST Studio, fabricated on an FR-4 substrate, and experimentally tested using a Vector Network Analyzer (VNA). Key performance parameters, such as return loss, VSWR, bandwidth, and impedance matching, will be analysed and compared with simulation results. The study contributes to the development of low-cost, high-performance dual-band antennas to enhance spectrum efficiency and reduce hardware complexity. The outcomes are relevant to modern wireless technologies, including Wi-Fi, Bluetooth, wireless bridging and future communication systems such as Wi-Fi 6 and 5G.

2. Methodology

Fig.1 shows the overall workflow of the dual-band microstrip patch antenna project. The process begins with a background study to understand antenna design principles, followed by designing the antenna based on the target frequencies of 2.4 GHz and 5.0 GHz. The antenna is then modelled and simulated in CST Studio software using a U-slot structure to achieve dual-band operation. The simulated performance is evaluated based on resonant frequency and return loss. If the desired performance is not achieved, the design parameters are optimised and re-simulated. Once acceptable results are obtained, the antenna is fabricated and experimentally tested. Finally, the measured results are analysed and compared with simulation results to validate the performance of the proposed antenna.

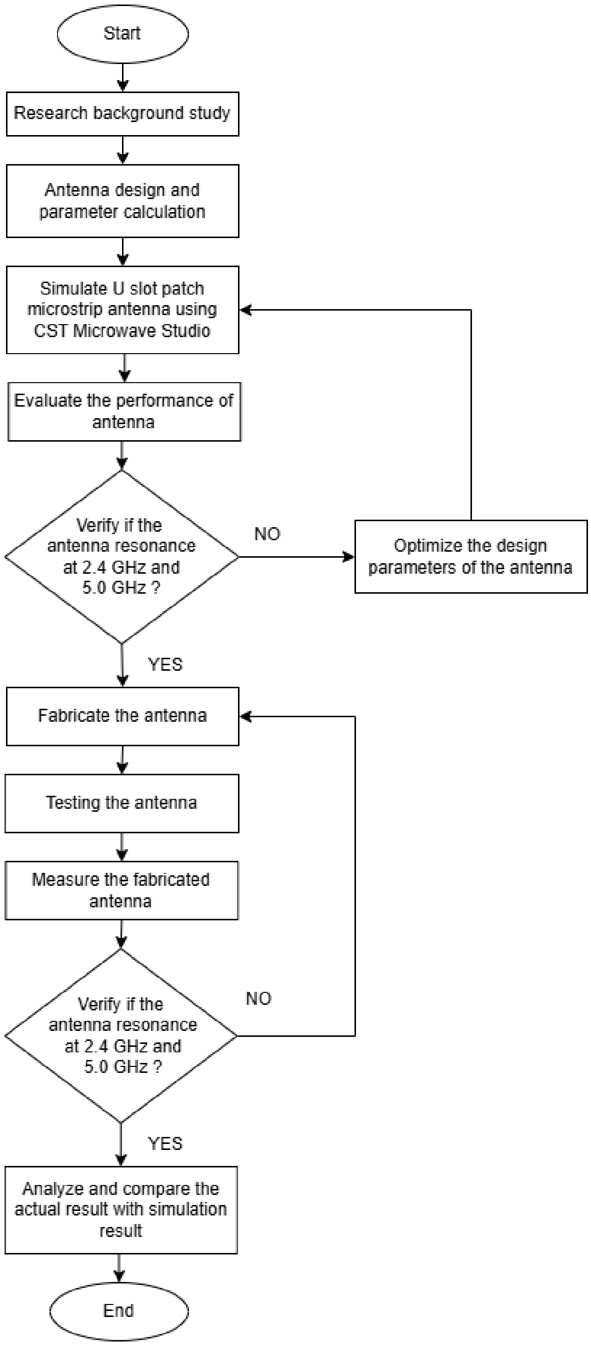


Fig. 1 *Flowchart of the project*

2.1 Proposed Antenna Design Specifications

Fig. 2 and Table 1 show the specifications and optimised parameters of the proposed dual-band microstrip patch antenna. The antenna is printed on a 1.6 mm thick FR-4 substrate ($\varepsilon_r = 4.3$) with overall dimensions of 76 mm x 59 mm. The radiating patch and 50 Ω microstrip feed line are on the top surface, while the ground plane is on the opposite side. A standard SMA connector facilitates connection to other communication devices. The patch, feed line, inset and U-slot dimensions were carefully optimised through simulation to achieve dual-band operation at 2.4 GHz and 5.0 GHz with return loss below -10 dB to ensure proper impedance matching and reliable performance.

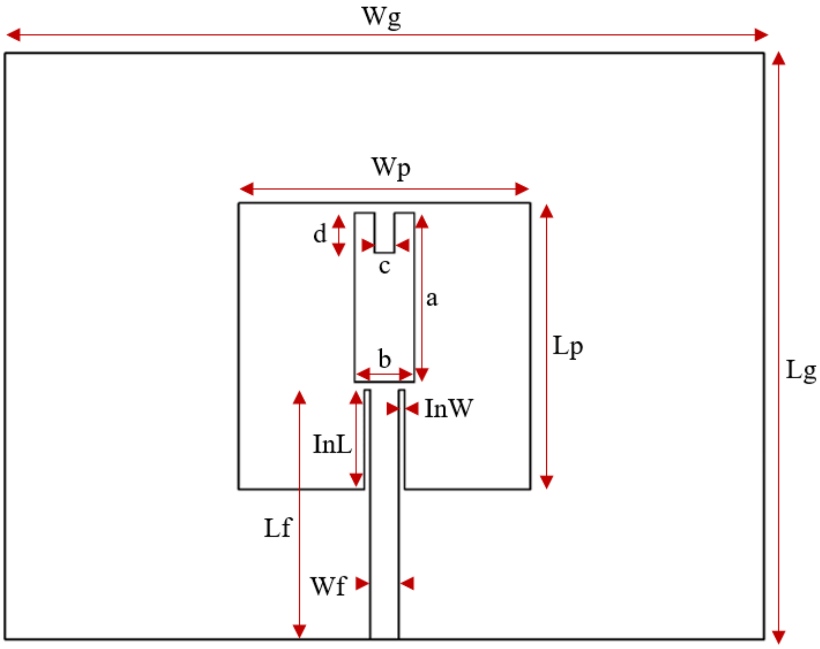


Fig. 2 *Specifications of the proposed dual-band microstrip patch antenna*

Table 1 *The optimised parameters of antenna design*

Parameter	Optimise Value (mm)
Wg	76
Lg	59
hg	0.035
hs	1.6
Wp	29.2
Lp	28.8
Wf	2.86
Lf	Lg/2 – Lp/2
InW	0.6
InL	10
a	12
b	6
c	2
d	4

Fig. 3 illustrates that the final antenna design includes a port at the end of the feed line, which is essential for exciting the antenna and analysing parameters such as return loss (S11). The antenna is enclosed within a bounding box to simulate the surrounding air or free-space environment, allowing accurate computation of radiation, reflection and other electromagnetic behaviours during simulation.

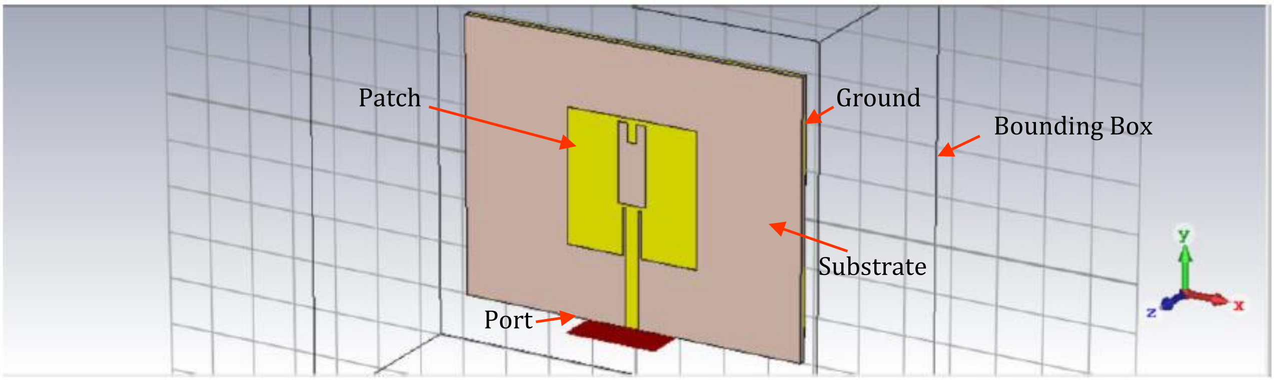


Fig. 3 *Final proposed antenna Design in CST Studio software*

2.2 Process of Fabrication

Fig. 4 illustrates the fabrication process of the microstrip patch antenna. The process begins with the finalised antenna design developed in CST Studio, ensuring it meets the required performance specifications. The antenna layout is then transferred to AutoCAD to prepare an accurate geometry for fabrication. This pattern is printed onto a dry film, which serves as a photomask, and then laminated onto an FR-4 epoxy board. The board is exposed to ultraviolet (UV) light to transfer the antenna pattern onto the photosensitive layer, followed by development to remove unexposed areas. Next, the board undergoes chemical etching using Ferric Chloride to remove unwanted copper, leaving the antenna structure intact. A stripping process is then performed to remove the remaining dry film. Fig. 5 shows the final fabricated microstrip patch antenna with a coaxial cable connected via an SMA connector, then ready for measurement and testing.

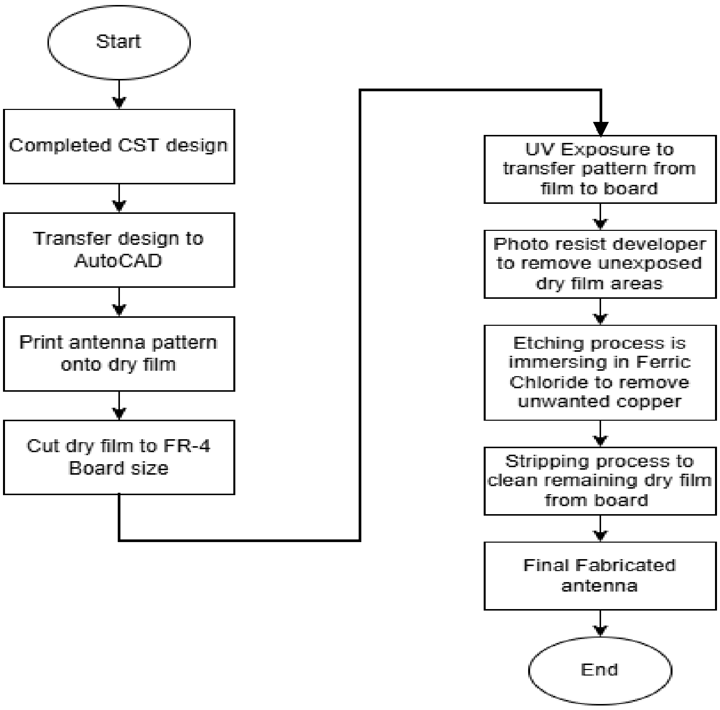
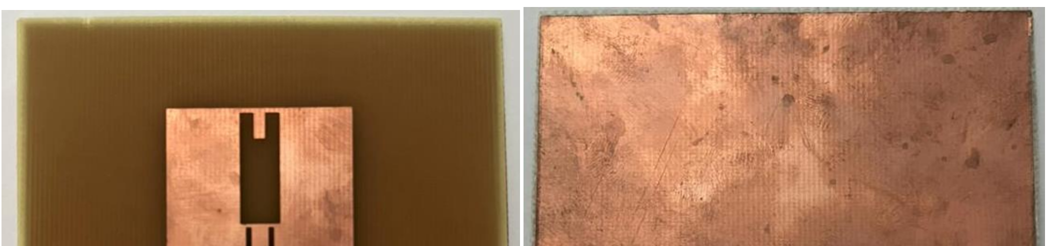
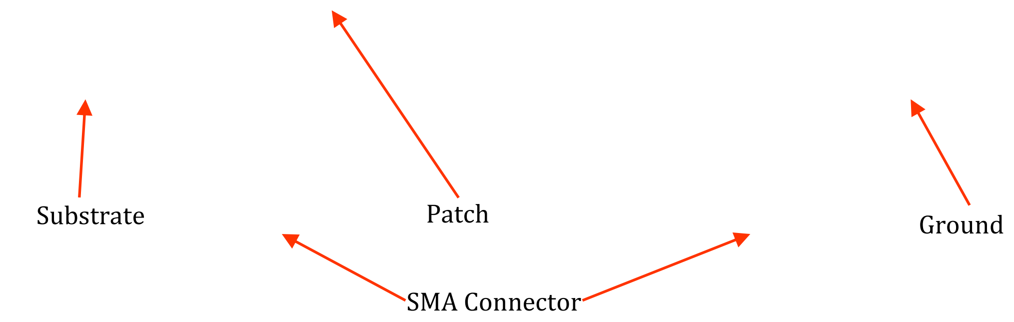


Fig. 4 *Flowchart of the fabrication process of antenna design*





(a) **(b)**

Fig. 5: *Fabricated dual-band microstrip patch antenna (a) Top view (b) Bottom view*

2.3 Process of Implementation Dual-Band Microstrip Patch Antenna for Wireless Bridging at 2.4 GHz and 5.0 GHz

Fig. 6 illustrates an overall network topology of the proposed point-to-point wireless bridging system using MikroTik L11UG-5HaxD devices and fabricated dual-band microstrip patch antennas. The internet connection from the ISP router is delivered via Ethernet to a MikroTik configured in AP Bridge mode using WinBox, where the Ethernet and wireless interfaces are bridged to enable transparent Layer-2 communication. This device acts as the transmitting node and sends the RF signal to the fabricated dual-band antenna operating at 2.4 GHz and 5.0 GHz.

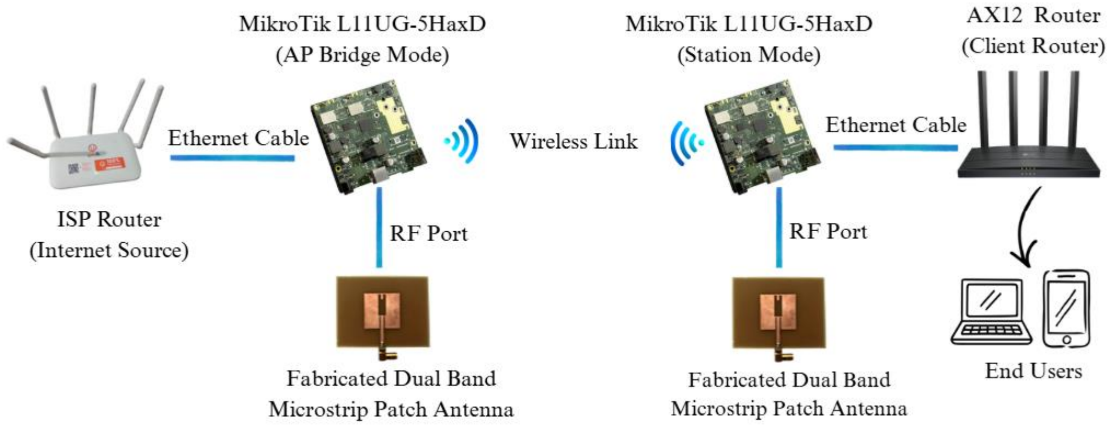


Fig. 6 *Network topology diagram*

On the receiving side, a second fabricated antenna captures the signal and feeds it to another MikroTik configured in Station mode with matched wireless parameters to ensure stable and reliable connectivity. The station device bridges its wireless and Ethernet interfaces to forward traffic transparently without routing or NAT. The Ethernet output is then connected to an AX12 router to distribute the bridged internet connection to local users. Overall, the figures demonstrate how a wired ISP connection is extended wirelessly using proper MikroTik configuration and fabricated dual-band antennas to achieve seamless and reliable network connectivity.

3. Result and Discussion

This section presents the results obtained from the design, simulation and implementation of the proposed dual-band microstrip patch antenna. The discussion focuses on three main aspects, which are the radiation pattern characteristics, a comparison between simulated and measured performance, and the implementation of the wireless bridging system (WBS) using the fabricated antennas. These results provide insight into the antenna's functionality and validate its suitability for point-to-point wireless bridging applications at 2.4 GHz and 5.0 GHz.

3.1 Radiation Pattern

Fig. 7 illustrates the 3D far-field radiation pattern of the antenna at 2.4 GHz, showing a typical broadside radiation characteristic with maximum radiation directed along the +z-axis. The antenna exhibits a moderate directivity of 6.838 dBi and a measured gain of approximately 1.6 dBi, indicating that a portion of the radiated power is lost due to efficiency limitations. The radiation and total efficiencies of -5.142 dB and -5.233 dB, respectively, suggest significant losses, likely caused by dielectric and surface wave losses as well as impedance mismatch. The radiation pattern features a broad main lobe with noticeable sidelobes and some backward radiation, which are commonly observed in microstrip patch antennas due to finite ground plane effects.

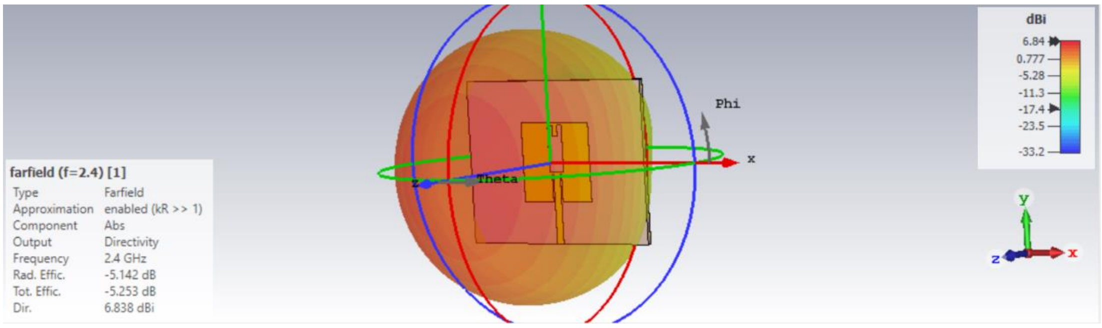


Fig. 7 *3D Far-Fields Abs at 2.4 GHz*

Fig. 8 shows the 3D far-field radiation pattern of the antenna at 5.0 GHz, which exhibits a directional broadside radiation characteristic similar to the 2.4 GHz band with the main lobe oriented normal to the patch surface. The antenna achieves a peak directivity of 5.972 dBi and a gain of approximately 2.3 dBi, showing improved radiated power compared to the lower band. The radiation efficiency (-3.603 dB) and total efficiency (-3.669 dB) demonstrate lower losses than at 2.4 GHz, likely due to better impedance matching and reduced dielectric losses. Although the radiation pattern is broader with more noticeable sidelobes, the antenna shows better efficiency and overall performance at 5 GHz is making this band more favourable for effective power transfer and wireless bridging applications.

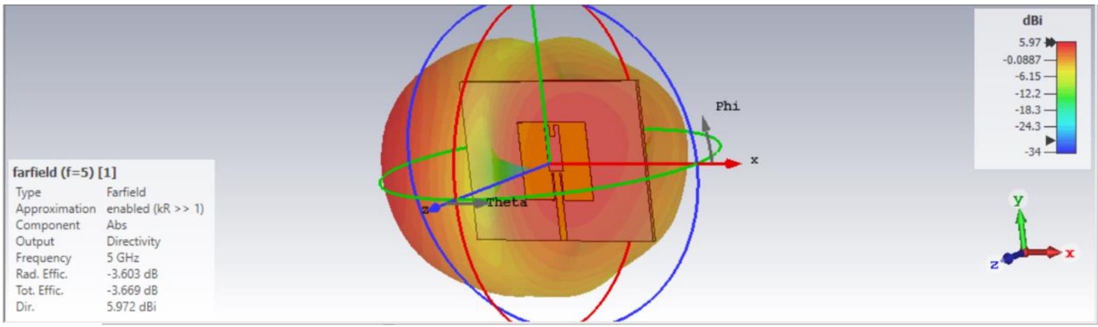


Fig. 8 *3D Far-Fields Abs at 5.0 GHz*

3.2 Comparison Result Between Measurement and Simulation of Return Loss, S11

Fig. 9 shows the comparison between simulated and measured S11 return loss of the proposed dual-band microstrip patch antenna. The simulated results show resonances at 2.4 GHz and 5.0 GHz with minimum S11 values of -15.9 dB and -20.6 dB, respectively, indicating good impedance matching. The measured results confirm dual-band operation with resonances at 2.4 GHz and 5.2 GHz, achieving S11 values of -22.9 dB at 2.4 GHz and -14.0 dB at 5 GHz. Minor discrepancies between simulation and measurement are attributed to fabrication tolerances and measurement uncertainties, while overall agreement validates the antenna's effective dual-band performance.

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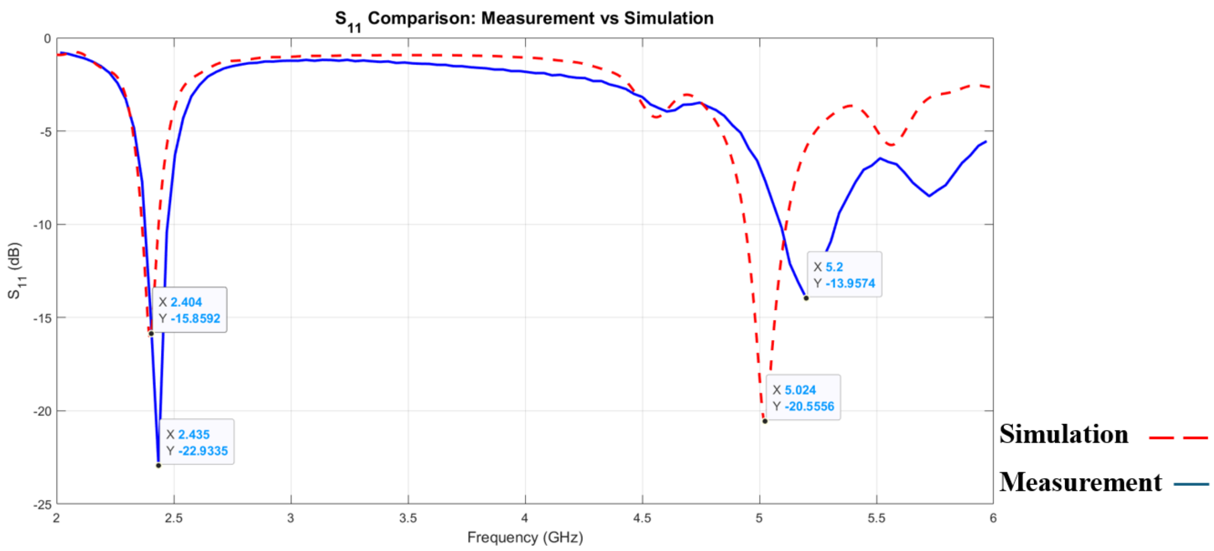

Fig. 9 *Comparison results between measurement and simulation of return loss, S11*

3.3 Comparison Result Between Measurement and Simulation of VSWR

Fig. 10 presents the comparison between simulated and measured VSWR of the proposed dual-band microstrip patch antenna. The simulated results show minimum VSWR values of 1.46 at 2.4 GHz and 1.21 at 5.02 GHz, which shows excellent impedance matching. The measured VSWR values are 1.15 at 2.435 GHz and 1.50 at 5.2 GHz, all of which remain below the acceptable VSWR < 2 criterion. Minor discrepancies between simulation and measurement are attributed to fabrication tolerances and material variations, while the overall results confirm reliable dual-band antenna performance in practical implementation.

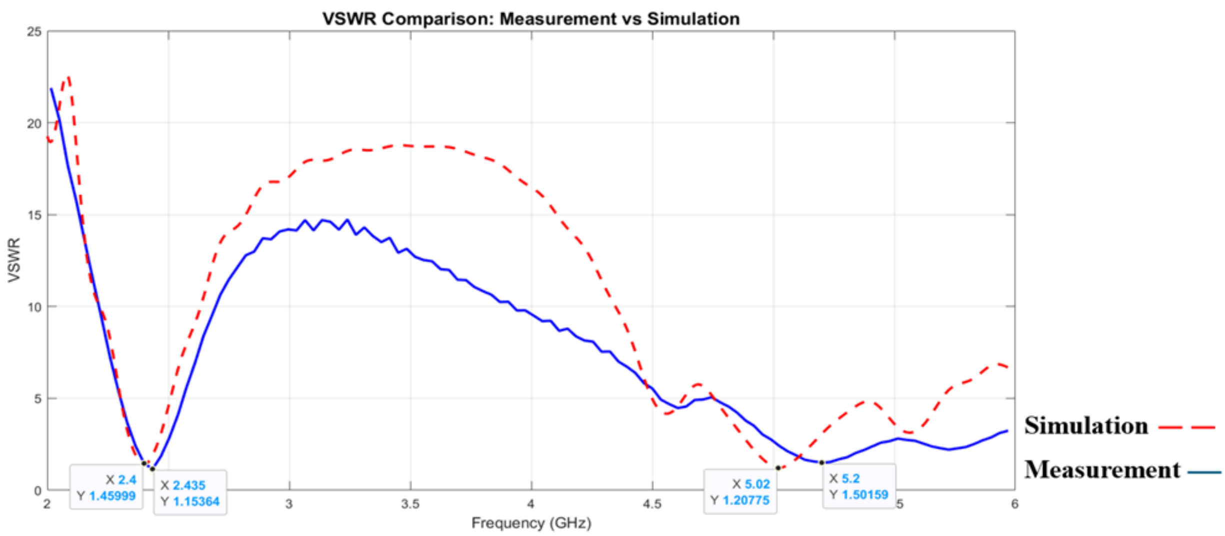

Fig. 10 *Comparison results between measurement and simulation of Voltage Standing Wave Ratio (VSWR)*

3.4 Implementation Dual-Band Microstrip Patch Antenna for Wireless Bridging at 2.4 GHz and 5.0 GHz for 20 meters

Fig. 11 shows the speed test results at the access point and their corresponding performance. The system is installed at the owner's house, where the home router subscribed to a 100 Mbps UniFi plan serves as the internet source and is connected to a MikroTik L11UG-5HaxD configured in AP Bridge mode with the fabricated dual-band microstrip patch antenna. The speed test conducted on the home Wi-Fi network achieved a download speed of approximately 120 Mbps, exceeding the subscribed plan due to favourable network conditions, strong signal quality, low interference and temporary bandwidth bursting by the ISP.

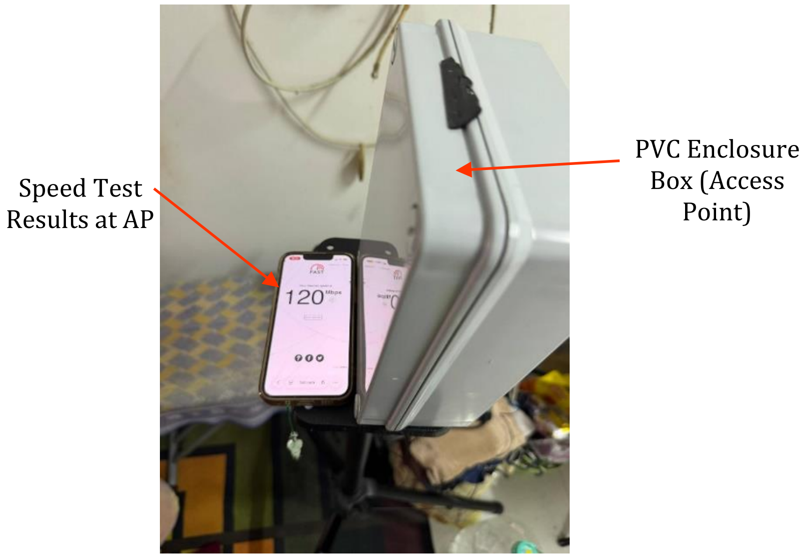

Fig. 11 *Speed test results at the access point using home Wi-Fi*

Fig. 12 shows the speed test results at the client and the performance of the wireless bridging system. The client point is located 20 meters from the access point at a neighbouring house, where a MikroTik L11UG-5HaxD configured in Station mode is connected to a fabricated dual-band microstrip patch antenna and an AX12 router for user distribution. The measured client-side speed test achieved a download speed of 74 Mbps, which is lower than the access point result due to free-space path loss, environmental interference and antenna alignment factors. Nevertheless, the short distance and partial line-of-sight conditions help maintain a stable wireless link its confirming the practicality of the proposed antenna for short-range point-to-point wireless bridging.

Fig. 12 *Speed test Results at the client point using AX12 router*

4. Conclusion

This project successfully developed a compact dual-band microstrip patch antenna operating at 2.4 GHz and 5.0 GHz for wireless bridging. The antenna is fabricated on an FR-4 substrate with microstrip line feed and optimised slots, showing good impedance matching and efficient radiation with measurements closely matching simulations. It was implemented in a 20-meter point-to-point wireless bridging system, achieving 120 Mbps at the access point and 74 Mbps at the client, showing a stable and reliable link. Minor performance differences were attributed to fabrication tolerances and environmental factors. Overall, the project met all objectives and produced a cost-effective and functional antenna suitable for Wi-Fi and short-range wireless bridging.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm their contributions to the paper as follows: study conception and design: Syamila Salim and Ramlee Kamarudin; ***data collection:*** *Syamila Salim;* ***analysis and interpretation of results:*** *Syamila Salim;* ***draft manuscript preparation:*** *Syamila Salim. All authors reviewed the results and approved the final version of the manuscript.*

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