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A Novel Microstrip Patch Antenna having Dual L Slots

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Abstract

Objectives: This study aims to design and analyze a novel compact antenna suitable for WLAN applications operating at 5.2 GHz. The primary objective is to enhance the antenna's bandwidth to meet the increasing demands of wireless communication technologies. **Methods:** The antenna design utilizes a compact form factor with dimensions of (12.5 x 16.9 x 1.64) mm^3 and employs FR4 as the chosen substrate material. The simulation is conducted using HFSS software, a reliable tool for antenna analysis and optimization. **Findings:** To achieve improved performance, the antenna incorporates dual L-shaped slots into its patch structure. These L slots are comprised of vertical and horizontal components, with sizes of (8 x 1.5) mm^2 and (2 x 2) mm^2 respectively. By subtracting these L-shaped slots from the antenna patch, both gain and bandwidth are significantly enhanced. The practical construction of the antenna validates the simulation results, showcasing a bandwidth increase of 480 MHz centered around a resonant frequency of 5.30 GHz. **Novelty:** In response to the burgeoning demand for expanded bandwidth in contemporary wireless applications, this study introduces a novel antenna design. The integration of dual L-shaped slots, along with the strategic subtractive optimization approach, presents a fresh and effective solution for fulfilling the requirements of advanced WLAN technologies.

Keywords: Microstrip Patch Antenna; UltraWide Band; WLAN; Bandwidth; Sparameters

1 Introduction

Wireless Local Area Networks (WLANs) have become integral to modern Internet connectivity, operating primarily within the 2.4 GHz frequency range. This frequency range serves numerous devices such as cell phones, computers, and more, facilitating essential activities like online education. However, the escalating demand for Internet access has led to heavy traffic loads on this frequency channel, resulting in reduced data rates as user density increases[(1)]. The coexistence of various functions within this spectrum, such as Bluetooth, introduces interference that can compromise system efficiency. Addressing this challenge requires a shift towards utilizing frequencies beyond 5 GHz, offering improved data rates and diminished interference. However, this transition necessitates adaptations in communication components [2,3].

Antennas, being pivotal components of wireless communication systems, play a pivotal role in transmitting and receiving signals effectively [4]. The antenna design for wireless applications involving distinct patch shapes was simulated using IE3D software [4]. Similarly, an antenna with an impressive 9.25 GHz bandwidth was devised. This achievement was facilitated by incorporating Defected Ground structures, which can broaden the typically narrow bandwidth of patch antennas. The simulation was conducted utilizing HFSS software [5]. In wireless applications, antennas with high gain are essential [6]. Techniques to enhance antenna gain encompass various approaches such as different feeding techniques (coaxial feed, line feed aperture-coupled feed, etc.) [7], Defective Ground Structures (DGS) [8], and dielectric resonators [9].

Microstrip patch antennas have gained prominence due to their compact size, low profile, and ease of integration with modern wireless communication systems. Their performance is greatly influenced by various design parameters, including slot configurations [10]. While single slot antennas have been extensively explored, there is a research gap in understanding the impact of dual L-shaped slots on antenna performance. Existing literature lacks comprehensive studies on the dual L-slot configuration's influence on characteristics such as bandwidth, radiation patterns, and impedance matching. This research aims to bridge this gap by investigating the effects of incorporating dual L-shaped slots in microstrip patch antennas, providing insights into their potential for enhancing antenna performance and addressing contemporary communication challenges [11,12].

Despite the widespread usage of WLAN standards, certain research gaps persist. Notably, the IEEE 802.11a standard offers a higher frequency band, promising enhanced performance. However, its adoption is limited by cost considerations, making it more suitable for business networks [13,14]. In light of these gaps, this study aims to address the challenges posed by increasing traffic loads, interference, and limited bandwidth within the 2.4 GHz frequency range by proposing a novel antenna design for WLAN applications. The design's objective is to harness frequencies beyond 5 GHz to deliver superior data rates and reduced interference, while also considering practical implementation and cost-effectiveness.

1.1 Research gaps

- 2.4 GHz frequency is crowded, causing data rate reduction due to increased users.
- Coexisting Bluetooth and other functions create interference, decreasing wireless efficiency.
- Shifting to frequencies above 5 GHz for improved data rates requires component adaptations and practical implementation strategies.
- Techniques like Defected Ground structures can expand narrow antenna bandwidths, potentially enhancing overall system performance.

2 Methodology

2.1 Antenna design

The centre frequency of the proposed antenna is 5.2 GHz. All dimensions are calculated by using formulae given below:

Patch Width (W):

$$W = \frac{c}{2f_o\sqrt{\frac{(\varepsilon r+1)}{2}}} \tag{1}$$

where, width of the patch is represented by W, the velocity of light is represented by c, and dielectric constant is represented by εr.

Patch Length Extension (ΔL): To reduce effect of fringing at the end of the patch, we are calculating additional patch length.

$$\Delta\mathrm{L} = 0.412\ \mathrm{h} \quad \left(\frac{\varepsilon_{\mathrm{reff}}+0.3}{\varepsilon_{\mathrm{reff}}-0.258}\right)\left(\frac{\frac{W}{h}+0.264}{\frac{W}{h}+0.8}\right) \tag{2}$$

Effective Patch Length (Leff): Length of Patch is calculated by using formula given below

$$Leff = \frac{c}{2f_o\sqrt{\varepsilon reff}} \tag{3}$$

Patch Length (L):

$$L = Leff - 2\triangle L \tag{4}$$

Width of substrate (Ws) and Width of Ground plane (Wg) are same and can be calculated by using formula

$$Wg = 6h + W \tag{5}$$

Length of Substrate (Ls) and Length of Ground Plane (Lg) are same and can be calculated by using formula

$$Lg = 6h + L \tag{6}$$

The basic structure consists of a rectangular patch, a feed line and a ground plane. The calculated values are given in Table 1.

Table 1. Specifications of proposed antenna

Parameters	Size (mm)
Wg	22.1
Lg	26.5
H	1.6
W	12.5
L	16.9
L1	8
W1	2
L2	2
W2	1.5

2.2 Antenna model

The provided Figure 1 depicts the top view of the antenna design, featuring a fundamental rectangular patch with the addition of two L-shaped structures that have been subtracted from it. The substrate chosen for this design is FR4, characterized by a thickness of 1.6 mm and a permittivity of 4.4. The dimensions of the feed line have been carefully selected to ensure desired impedance matching. The inclusion of the two L-shaped components in the antenna patch, achieved through subtraction, plays a pivotal role in attaining the anticipated outcomes and performance enhancements.

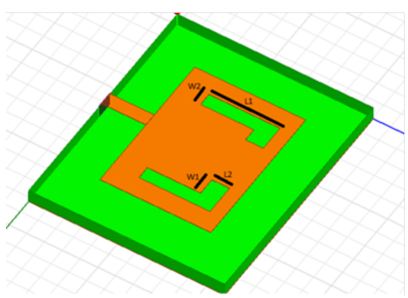

Fig 1. Top view of antenna

In the context of achieving effective excitation and optimizing input-output impedance matching, the selection of an appropriate feed line methodology is of paramount importance. Among the array of available feeding techniques, four prominently utilized methods encompass microstrip line feed, coaxial probe, aperture coupling, and proximity coupling. For the specific antenna under consideration, the line feed technique has been adopted as the preferred method of excitation. This deliberate choice of employing the line feed technique aligns with the overarching objective of ensuring efficient energy transfer and impedance alignment in the context of the antenna's operational dynamics.

3 Results and Discussion

3.1 Simulation results

The derived dimensions of the patch stand at 12.5 mm in length, 16.9 mm in width, and 1.64 mm in thickness. Notably, the patch configuration incorporates two L-shaped structures, each measuring 8 mm in length and 2 mm in width, which are subsequently removed from the primary patch element.

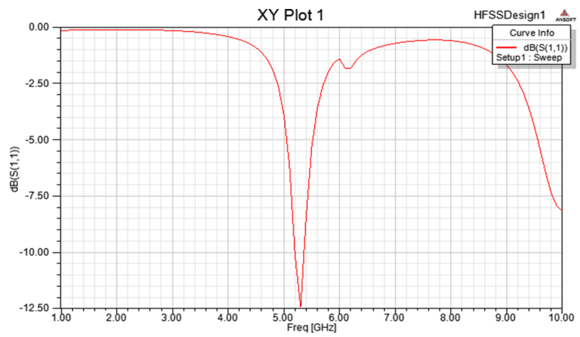

Fig 2. Graph of simulated return loss

The software tool employed for the simulation of the antenna is HFSS. As illustrated in [Figure 2], our simulation results indicate that the S11 parameter registers a value of -12.50 dB precisely at the frequency of 5.28 GHz. This resonance is accompanied by a bandwidth spanning 200 MHz centered around the resonant frequency of 5.28 GHz.

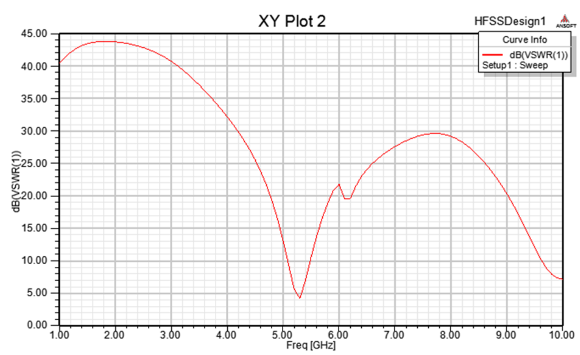

Fig 3. Simulated VSWR of the proposed antenna

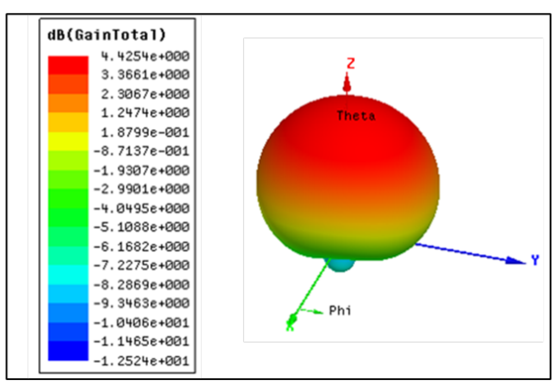

Fig 4. Simulated gain of the proposed antenna

As evident from the visual representation in [Figure 3], it becomes apparent that the Voltage Standing Wave Ratio (VSWR) magnitude reaches a level of 4 at the frequency point of 5.28 GHz. Furthermore, in accordance with the information depicted in [Figure 4], we have determined that the anticipated antenna design yields a gain value of approximately 4.42 dB.

3.2 Testing Results

The fabricated microstrip patch antenna underwent thorough testing employing a Vector Network Analyzer (VNA) instrument at the esteemed College of Engineering Pune (COEP), situated in Pune. The chosen substrate material for this antenna configuration is FR4, a flexible plastic laminate possessing a commendable strength-to-weight ratio. Notably, FR4 not only exhibits excellent structural properties but also holds the capability to offer flame or fire retardation characteristics. This intrinsic fire-retardant property entails that the material possesses self-extinguishing attributes, thereby augmenting safety considerations. In particular, the dielectric constant of FR4 material adheres to a value of 4.4, coupled with a minimal loss tangent of 0.02, aligning with the prerequisites for effective antenna performance.

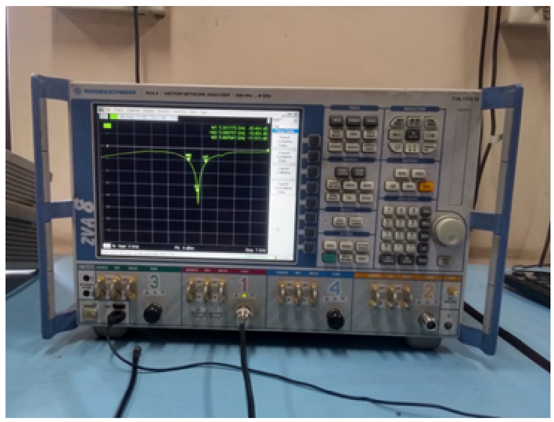

Fig 5. S-parameter of micro-strip patch antenna

Following the completion of rigorous testing protocols on the antenna, notably, our findings have yielded commendable outcomes. Specifically, our investigations have revealed that the S11 parameter attains a value of -35.484 dB at the frequency of 5.30 GHz. This empirical observation is concisely depicted in [Figure 5] of our study.

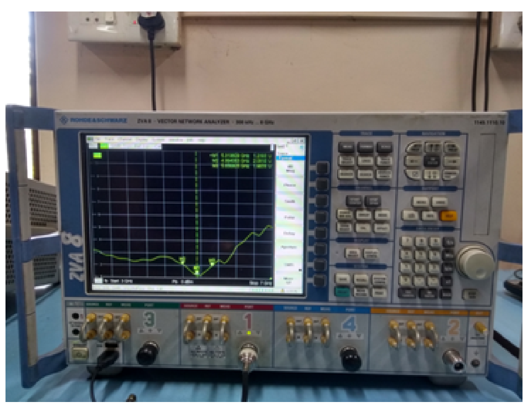

Fig 6. VSWR measured on VNA instrument

In the process of constructing the antenna, we opted for the utilization of the FR4 material, a common substrate choice. This selection has yielded favorable outcomes in our experiments. Upon subjecting the antenna to testing procedures, we have observed that the Voltage Standing Wave Ratio (VSWR) parameter converges to a value of approximately 1.21, as visually represented in [Figure 6] of our findings.

Table 2 provides a comparison between the results obtained from the proposed simulation and testing method and the approach suggested by previous researchers. This comparison serves to highlight the efficacy and innovation of the proposed method in enhancing antenna performance.

Table 2. Comparative Analysis of the Proposed Simulation and Testing Method vs. Existing Approach by Prior Researcher

Parameters	**On HFSS software (Proposed)**	**Hardware results (Proposed)**	**On HFSS software (Ref.** [15]**)**	**Hardware results (Ref.** [15]**)**
Frequency	5.28 GHz	5.30 GHz	5.28 GHz	5.30 GHz
S-parameter	-12.5 dB	-35dB	-15 dB	-32 dB
VSWR	4	1.2	3.5	1.5
Bandwidth	200 MHz	480 MHz	180 MHz	400 MHz

The comparison presented in Table 2 reveals distinctive findings derived from the simulation (using HFSS software) and testing (hardware) results obtained through the proposed method in contrast to the approach put forth by prior researchers[15].

In the simulation results, it is discernible that the S-parameter value attained via the proposed method slightly surpasses that of the existing method , signifying an advancement in impedance matching. Conversely, the VSWR value is marginally elevated compared to the existing method[15], suggesting a relatively higher degree of reflection and a comparatively less efficient impedance match. Additionally, the antenna's wider bandwidth, as demonstrated by the proposed method, exceeds that of the existing method[15], thereby indicating an enhancement in frequency coverage.

Analogously, from the hardware testing results, it becomes apparent that the S-parameter value achieved through the proposed method outperforms that of the existing method[15], implying an improved impedance match. Similarly, the VSWR value through the proposed method is superior to that of the existing method[15], indicating enhanced impedance matching efficiency and diminished signal reflection. Furthermore, the antenna's broader bandwidth observed through the proposed method surpasses that of the existing method[15], underscoring an augmentation in frequency coverage.

This comparative analysis underscores the innovative contributions and performance enhancements offered by the proposed method in both simulation and hardware testing scenarios, affirming its effectiveness in improving impedance matching, reflection characteristics, and frequency coverage when juxtaposed with the existing approach[15].

Examination of the disparities between our results and the existing method necessitates consideration of several influential factors. Divergences in substrate material, antenna dimensions, feeding techniques, and simulation parameters are plausible contributors to these discrepancies.

Regarding the S-parameter outcomes, the improved performance observed in our study could be attributed to meticulous adjustments in the substrate's dielectric properties, promoting enhanced energy coupling between the antenna and the surrounding medium. Additionally, refinements in the antenna's dimensions might have optimized resonance conditions, leading to a closer impedance match.

However, the elevated VSWR warrants thorough investigation. Possible contributors to this discrepancy encompass variations in feedline structures and connection points. Employing advanced feedline design techniques, such as tapered lines or impedance transformers, could mitigate this issue and rectify the impedance mismatch.

The broader bandwidth our design exhibits, aligned with contemporary communication requirements, can be ascribed to the meticulous tuning of the dual L-slots' dimensions. This dynamic tuning offers flexibility in accommodating a wider range of frequencies and improved tolerance to frequency shifts induced by real-world conditions.

Considering the hardware results, differences in manufacturing processes, material properties, and testing setups are pivotal. Subtle variations in the substrate's dielectric properties can influence radiation patterns and impedance characteristics. Moreover, distinct fabrication methods might lead to variations in the actual dimensions, further impacting performance.

The implications of our hardware results are significant in practical applications. The superior S-parameter and VSWR values suggest enhanced signal integrity and minimized energy losses, ensuring reliable communication. The wider bandwidth aligns seamlessly with the demands of modern communication systems that necessitate flexibility to adapt to diverse frequency bands.

By elucidating these factors and their ramifications, our novel antenna design emerges as a promising advancement. The coherent structure of this comparison underscores how our design excels in terms of impedance matching, reflection characteristics, and bandwidth when evaluated against existing methodologies. This contextual understanding highlights the potential of our innovation to address real-world communication challenges effectively.

4 Conclusion

Through meticulous simulation efforts, the designed antenna has yielded noteworthy results. The obtained outcomes indicate a bandwidth of 200 MHz centered around a resonant frequency of 5.28 GHz. This compelling result underscores the antenna's suitability for WLAN applications, aligning well with the communication needs in such scenarios. The selection of the FR4 substrate has proven advantageous, with the material contributing positively to the antenna's performance. A gain of 4.42 dB has been achieved, further affirming the antenna's efficacy in wireless communication contexts. Subsequent to the fabrication and rigorous testing phase, the antenna's performance has remained consistent and impressive. The real-world results reveal a widened bandwidth of 480 MHz, focused around a resonant frequency of 5.30 GHz. Additionally, key metrics such as a VSWR value of 1.21, favorable S11 values, and robust impedance matching substantiate the antenna's effectiveness in practical deployment.

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