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Slot-loaded Dual-Band Microstrip Patch Antenna for 5G and WLAN/WiMAX Wireless Applications

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Abstract

Objectives: This study introduces a dual-band rectangular microstrip patch antenna with a slot-loaded, specifically designed for 5G and WLAN/WiMAX applications. **Method:** The antenna is mounted on a substrate material of Rogers AD255C material having ε_r of 2.55 and a thickness of 1.56 mm. Three slots are etched on the conventional rectangular microstrip patch antenna. A 50-ohm microstrip line powers the antenna. The antenna that has been suggested is created and simulated using CST Studio Suite 2020. **Findings:** Based on numerical simulation, the proposed antenna functions at 3.5 GHz and 5.8 GHz, suitable for 5G and WLAN/WiMAX wireless technologies. The antenna offers measured return loss (S11) of -22.10 dB and -22.9 dB and a Gain of 4.43 dBi and 4.62 dBi at 3.5 GHz and 5.8 GHz, respectively. The radiation patterns are linear and broadside. **Novelty:** This article aims to create a smaller planer dual-band antenna that integrates WLAN/WiMAX and 5G communication standards into a single device.

Keywords: Dual-band; 5G; WLAN; WiMAX; Microstrip patch antenna

1 Introduction

The field of wireless communication systems has seen a significant change in the past few years. To keep pace with the rapid expansion of wireless systems, it has become essential for antennas to resonate at a wide range of frequencies. Consequently, multiband and wideband antennas have become indispensable components of numerous communication systems such as WiFi, WLAN, and WiMAX.[(1)] With the increasing demand for ultra-small sizes in modern wireless communication devices, antenna size reduction has become essential. Creating small wideband/multiband antennas designed for portable communication devices is difficult due to the requirement to achieve numerous criteria, including wide bandwidth, symmetric radiation pattern, consistent gain, compact size, lightweight, and easy fabrication. Recently, there has been increasing attention in searching antennas to cover multiple frequency bands such as S-band (2–4 GHz), WiMAX (3.3–3.8 GHz), 5G mid bands (3.3–3.8 GHz, 4.4–4.9 GHz), C-band (4–8 GHz), WLAN (5.15–5.825 GHz), UWB

(3.1–10.6 GHz), X-band (8–12 GHz) due to the numerous operating necessities of communication devices.[2] A multi-band antenna can be achieved by adding a slot in the patch or ground plane at specific locations on a narrow band microstrip patch antenna. Suppose the length of the slot is either a quarter-wavelength or a half-wavelength at an appropriate location on the patch/ground plane. In that case, it stimulates the higher modes near the fundamental mode, enabling several operating bands.[2]

Researchers have designed numerous antennas for WLAN and WiMAX applications. In[3], a slotted PSPA (Plus-Shaped Patch Antenna) with DGS is modeled and proposed for 5G sub-6, and the WiMAX application is designed with a reflection coefficient of -52.06dB resonating at 3.12 GHz and operates with a broader bandwidth of 2.56 GHz (2.62-5.23 GHz). The PSPA is designed with good gain (2.44 dBi) and omnidirectional radiation characteristics. In[4], the antenna resonant at 3.4 GHz and 5.5 GHz is designed using a semicircular slot in the patch, and for the improvement of its bandwidth and gain, the DGS Structure technique is used. The antenna provides a good reflection coefficient of -48 dB and -44.5 dB, respectively, with 3.4 GHz and 5.5 GHz achieved gains of 2.72 dB and 3.87 dB. In[5], A dual wide band microstrip antenna with a double inverted F-shaped design is created for WLAN and WiMAX wireless communication. Two U-shaped patches are connected on a common plane to optimize gain and bandwidth and then adjusted in length to create an inverted F antenna. Reflection coefficients of –39.125 dB and –41.073 dB are obtained at resonant frequencies. In[6], The antenna is designed specifically to operate at frequencies ranging from 3.3 to 3.69 GHz and 5.15 to 5.25 GHz, facilitating dual-band operation. A compact metamaterial antenna has been proposed for WLAN and WiMAX applications. The authors in[7] Designed a rectangular antenna with a dual slot in the radiator that allows dual-band performance for WiFi, WLAN, and WiMAX frequencies. In[8], a dual-band antenna consisting of two pairs of crossed dipoles was introduced for WLAN and WiMAX bands. The authors in[9] have designed a dual-band antenna for WLAN applications, which includes slits and a rectangular split ring. In[10], A microstrip patch antenna was developed for resonating at the 2.4 and 5 GHz WLAN bands. According to, a C-shaped antenna was designed for WLAN and 5G applications.

Most antenna structures mentioned previously have significant drawbacks, such as requiring a large area, exhibiting narrow bandwidth, or overly complex. However, planar antennas offer an appealing alternative due to their potential for improved performance. These antennas have a low profile, which enables them to meet the multiband requirements of 5G and WLAN/WiMAX standards.

The primary aim of this essay is to formulate a compact planar dual-band antenna that implements both 5G and WLAN/WiMAX communication technologies into a single device. The suggested antenna design achieves simultaneous dual-band operation using a rectangular radiator with a rectangular slot, which operates by a Microstrip-fed method.

The proposed dual-band patch antenna covers the 5G and WLAN/WiMAX frequencies 3.5 GHz and 5.8 GHz, respectively. The proposed antenna was designed using a Rogers AD 255C material substrate. The proposed antenna is designed and developed, and its performance characteristics measurements are carried out using a standard simulation and measurement environment[11]. The design procedure, results, and conclusion are discussed in this paper.

2 Methodology

The input impedance can be controlled by varying the width (w) of the microstrip antenna. However, diminishing the input impedance to 50 Ω frequently requires an extremely wide patch antenna, which accounts for a large part of the critical space of the patch. The width further controls the radiation pattern. The height (h) of the substrate controls the bandwidth. The bandwidth can be increased by expanding the height (h). Increasing the height of the patch antenna increased its bandwidth. The thickness of the ground plane or microstrip is not vital. Regularly, the height h is much smaller than the wavelength of operation but should not be much smaller than 0.025 of a wavelength (1/40th of a wavelength), or the antenna efficiency will be degraded.

The permittivity of the substrate controls the fringing area, which has more extensive fringes and, thus, superior radiation. Diminished permittivity also increases the bandwidth of the antenna. The efficiency also increased with a lower permittivity value. Within the transmission-line model, the radiating slots are accepted to be separated by half the wavelength. The fringing electric field amplifies up to length ΔL on both sides along the patch length given in (Equation (1))[4,5].

$$\triangle L = 0.412h \frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{w}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{w}{h} + 0.8\right)} \tag{1}$$

The effective dielectric constants are given in Equation (2)

$$\varepsilon_{reff} = \frac{\varepsilon_{\gamma} + 1}{2} + \frac{\varepsilon_{\gamma} - 1}{2}\left[1 + 12\frac{h}{w}\right]^{-1/2} \tag{2}$$

The effective length of the patch is given in Equation (3) Leff=L+2ΔL. Where,

$$L_{eff}\frac{c}{2f_o\sqrt{\varepsilon_{eff}}} \tag{3}$$

The dual-band design begins with a primary rectangular patch radiator. First, the transmission-line model equations are used to design a patch at the fundamental resonance frequency of 3.5 GHz and 5.8 GHz with Rogers AD 255C substrate dielectric material having ε_r =2.5 and a thickness of 1.56 mm, as shown in Figure 1. Figure 2 demonstrates the evolution of the dual-band antenna to operate at the desired frequency band.

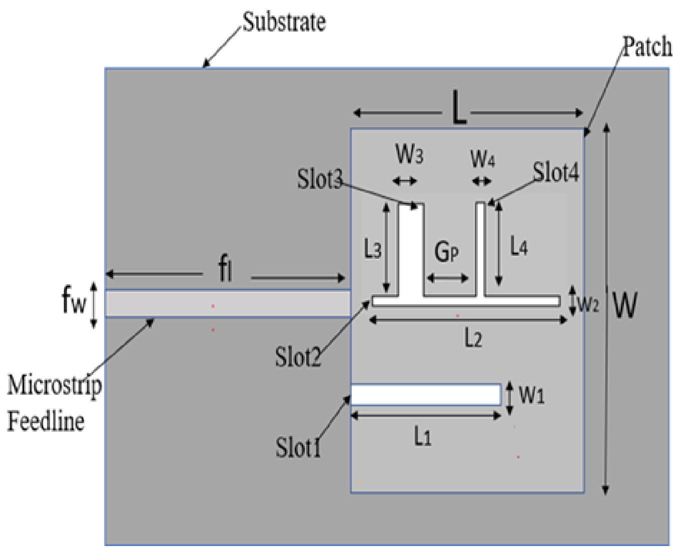
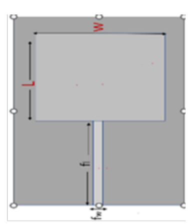
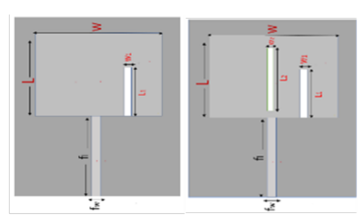


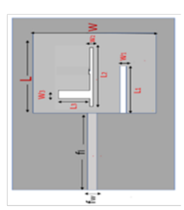
Fig 1. Geometry of the Proposed Dual Band Antenna



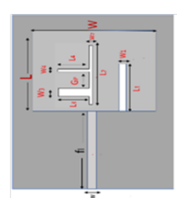
(a) Step 1, Frequency:5.8 GHz



(b) Step 2, Frequency:3.4 GHz and 5.6 GHz



(c) Step 3, Frequency: 3.5 GHz and 5.6 GHz



(d) Step 4, Frequency: 3.5 GHz and 5.8 GHz

Fig 2. (a)-(d) Proposed dual band antenna evolution

In step 1, as mentioned in Figure 2**(a)**, physical dimensions such as the length of a patch (L), width of the patch (W), and width of the feed line (fw) of the conventional rectangular patch are first calculated using Equations (1), (2) and (3) at 5.8 GHz. In step 2, as mentioned in Figure 2**(b)**, vertical slots are etched on the conventional patch, one at the center position and another on the right side, to obtain dual resonances at 3.4 GHz and 5.6 GHz. In step 3, as mentioned in Figure 2 **(c)**, a horizontal slot is etched at the bottom of the center vertical slot to achieve the resonant at 3.5 GHz and 5.6 GHz. In final step 4, as mentioned in Figure 2 **(d)**, another horizontal slot is etched at the middle of the center vertical slot to achieve resonant at a particular band at 3.5 GHz and 5.8 GHz for better impedance matching and improved radiation patterns. Further numerical studies on various physical dimensions are carried out for optimum performance. The antenna performance parameters are simulated. After numerical analysis of various physical parameters of slots, optimized physical parameters are mentioned in Table 1. The simulation is carried out using CST Studio Suite 2020.

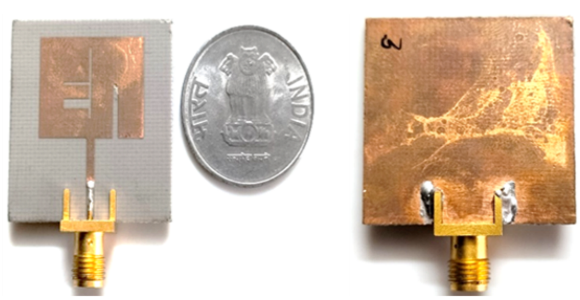
Table 1. Optimized Physical Parameters of the Proposed Antenna

Parameter	Size in mm	Parameter	Size in mm
Substrate Length (Ls)	30	Slot2 Length (L2)	11
Substrate Width (Ws)	30	Slot2 Width (W2)	0.5
Patch Length (L)	15.46	Slot3 Length (L3)	4.75
Patch Width (W)	19.38	Slot3 Width (W3)	1.5
Feed Length (fl)	12	Slot4 Length (L4)	4.85
Feed Width (fw)	1.40	Slot4 Width (W4)	0.5
Slot1 Length (L1)	8.3	Slot Gap (Gp)	2.09
Slot1 Width (W1)	1		

3 Results and Discussion

3.1 Antenna Fabrication and Measurement Results

The proposed dual-band antenna is fabricated and tested using a Vector Network Analyzer, and radiation patterns are measured in an anechoic chamber. Photographs of the fabricated antenna are shown in Figure 3.



(a) Top View (b) Bottom View

Fig 3. Photographs of the fabricated proposed antenna (a) Top View and (b) Bottom View

An experimental setup to measure radiation patterns is shown in Figure 4. Various antenna performance parameters are measured, such as return loss (S11), impedance bandwidth, resonant frequency, radiation pattern, and gain. The simulated and measured return loss (S_{11}) of the proposed antenna is shown in Figure 5.

Figure 5 shows that measured resonant frequencies are at 3.5 GHz and 5.8 GHz, which are well-matched with the simulated resonant frequencies with a return loss of -22.10 dB and -22.9 dB, respectively. Measured return losses at the resonant frequencies show good impedance matching at resonates. The measurement results are in good agreement with the simulated results.

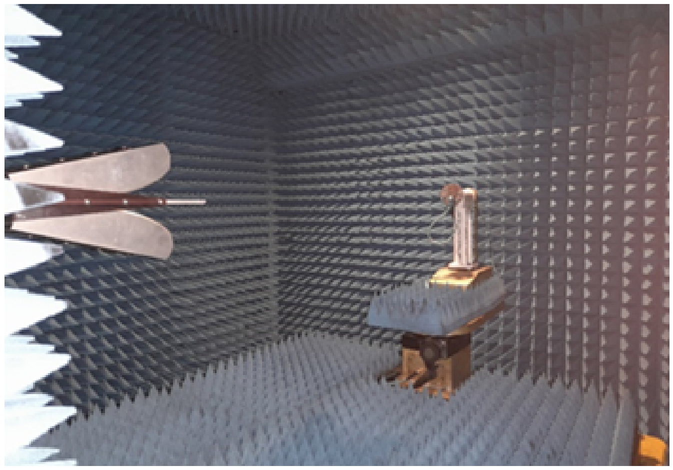


Fig 4. An Experiential setup to measure the radiation patterns at the Anechoic Chamber

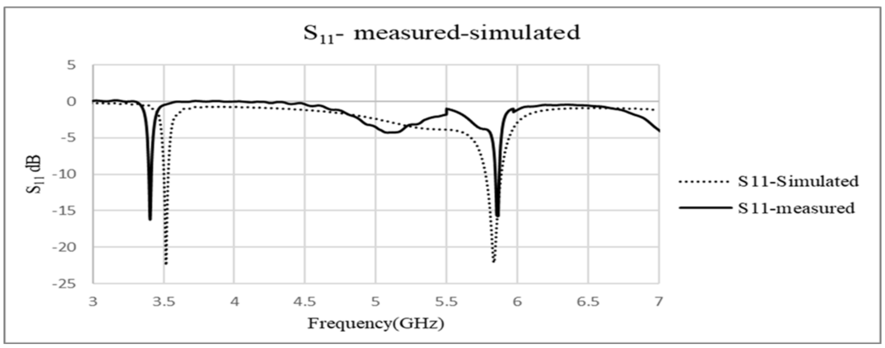


Fig 5. Comparison of measured and simulated return loss of the proposed antenna

Figure 6 shows measured and simulated co- and cross-polarized radiation patterns at 3.5 GHz and 5.8 GHz, respectively; Figure 6 shows a strong consensus between the simulated and measured radiation patterns. The radiation patterns are broadside, and cross-polarization levels are below -20 dB at boresight. Broadside radiation patterns are achieved due to slot-3 and slot-4 at the resonant frequencies. Measured gains at 3.5 GHz and 5.8 GHz are 4.21 dBi and 4.41 dBi, respectively, well-matched with simulated gains. Measured and simulated return loss and gain are listed in Table 2.

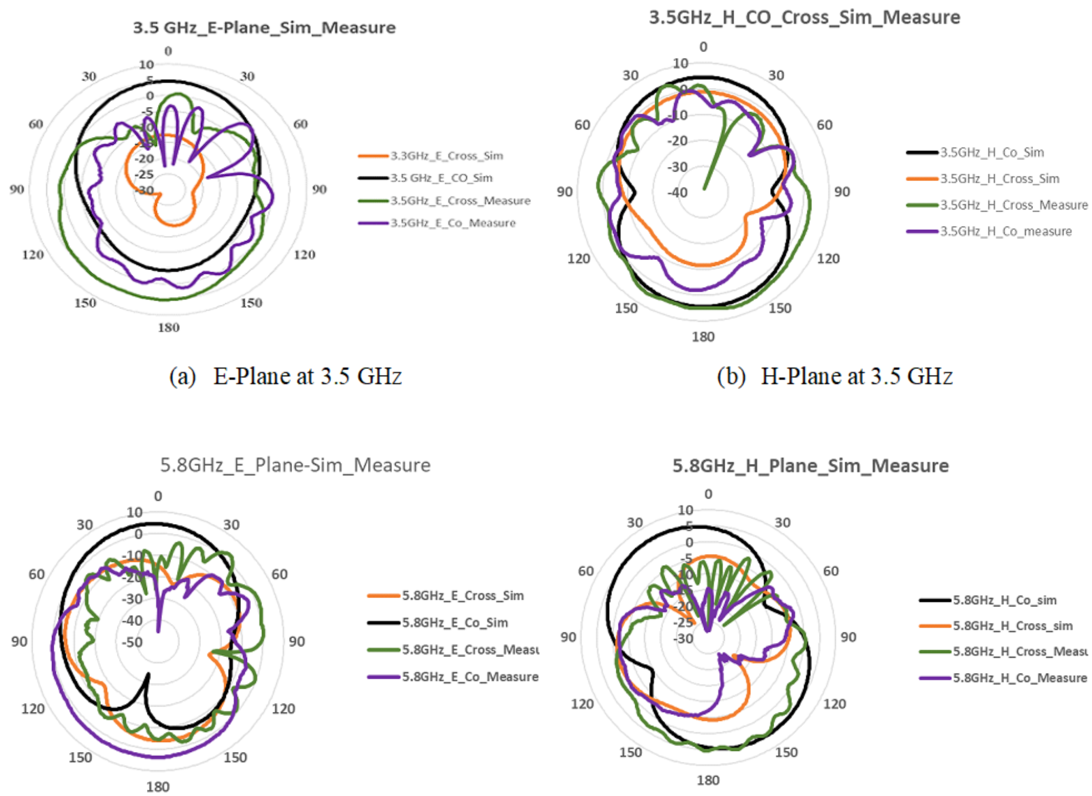
Table 2. Comparison of simulated and measured return loss and Gain

Frequency (GHz)	Simulated		Measured	
	Return loss (S_{11}) (dB)	Gain (dBi)	Return loss (S_{11}) (dB)	Gain (dBi)
3.5	-22.10	4.43	-16.22	4.21
5.8	-22.09	4.62	-15.71	4.41

Supplementary Table A presents a comparison of the proposed antenna with reported multiband microstrip antennas in terms of reported geometry, operating frequency, technique used, feeding technique, physical dimensions, operating frequencies, feeding technique, radiation pattern, Gain, and design methodology.

The literature on the reported antennas and **Supplementary Table A** shows that various geometries and techniques are used for multiple band operations. The proposed antenna structure is simple and smaller compared to the reported antennas. The proposed antenna also offers good gain. From the comparison, it can be observed that the proposed antenna is a good contender for the WiMAX and WLAN wireless applications. The proposed multi-band antenna offers a simple and low-complexity design. It also offers reasonable gain for the desired application.

Figures 5 and 6 show that the proposed antenna has dual frequency operation at the 5G and WLAN/WiMAX bands with significant gain and linear radiation patterns. This shows that the proposed antenna is a potential candidate for 5G-enabled



(a) E-Plane at 3.5 GHz (b) H-Plane at 3.5 GHz

(c) E-Plane at 5.8 GHz (d) H-Plane at 5.8 GHz

Fig 6. Simulated and measured radiation patterns of the proposed antenna at (a) E Plane at 3.5 GHz, (b) H Plane at 3.5 GHz, (c) E Plane at 5.8 GHz, and (d) H Plane at 5.8 GHz

devices and supports WLAN/WiMAX service. The minor variation in measured and simulated results is due to the fabrication tolerance, SMA connectors, and measurement setup.

4 Conclusion

This study presents a dual-band antenna in the 5G and WLAN/WiMAX frequency bands. The antenna is designed to resonate at 3.5 GHz and 5.8 GHz frequencies. The antenna uses the Rogers AD 255C dielectric substrate material with ε_r of 2.5 and a thickness of 1.56 mm. The design and construction of this is based on slot structure techniques. A noticeable impact on performance characteristics is noted due to the presence of slots in the antenna design. The proposed antenna offers a gain of 4.43 dBi and 4.62 dBi at resonant frequencies, respectively.

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