



A Simple Design of Microstrip Patch Antenna for WLAN Application Using 5.4 GHz Band

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Abstract. In this paper, a microstrip patch antenna for 5.4 GHz band has been designed using Computer Simulation Technology (CST) Microwave studio, choosing copper for constructing patch and ground plane, Flame Retardant 4 (FR-4) material for substrate and microstrip line for feeding. The small sized simple design offers high directivity as evident from a main lobe magnitude of 6.16 dBi and an impressive -53.189 dB S_{11} value at center resonant frequency of 5.38 GHz. Additionally, the efficiency is calculated to be 41.938% and the bandwidth an adequate value of 200.6 MHz. The Voltage Standing Wave Ratio (VSWR) value of 1.0044 indicates almost no mismatch between antenna and feedline. These simulated results confirm that the proposed antenna performs admirably despite the simple design and can be used for wireless local area network (WLAN) applications.

Keywords: Microstrip patch antenna · FR-4 material · CST microwave studio · Return loss · WLAN applications

1 Introduction

Modern wireless communication systems have undergone rapid growth in the last few decades, with the demand for wider bandwidth growing to support massive amounts of data necessary for high data rate applications. The radio frequency (RF) spectrum is becoming overcrowded with the evolution of wireless technologies like Bluetooth, Wi-Fi, WiMAX, GSM, satellite, Ultra-Wide Band (UWB) etc. [1]. The common frequency bands used for wireless local area network (WLAN) applications are 2.4 (2.417–2.497) GHz and 5 (5.15–5.35, 5.475–5.725) GHz. [2]. The 5 GHz networks are becoming more attractive compared to the traditional 2.4 GHz ones since 2.4 GHz spectrum is also shared by many other devices like cordless phones, microwave ovens, Zigbee devices, wireless peripherals, radars, audio-visual devices and so on. Efforts on antenna design for WLAN applications have persisted for the last few decades, but antenna engineering keeps encountering new challenges to meet the more rigid requirements for bandwidth, size, performance, cost and installation.

The choice for Antenna type is mostly determined by its purpose. Microstrip patch antennas have gained popularity in wireless communication applications due to their low cost, simplicity of fabrication, low weight, feed line flexibility, omnidirectional field pattern and integrability with solid-state devices [3]. The trade-off for the miniaturization in microstrip antenna is a small bandwidth, low gain and efficiency and possibility of fabrication error [4]. Researchers have employed a number of approaches to alleviate these problems, but these methods come with their own issues, such as increasing the substrate height (size increase and design is not low profile), defected ground structure (reduction of front to back ratio and field pattern change) [4], non-contacting feeding methods and metamaterials [5] (fabrication difficulty increase), PBG structure and multiple resonator effect (thickness increase) [6] etc.

The aim of this work is to propose a design for a microstrip patch antenna that uses the 5.4 GHz frequency band with a better performance over the most recent available work. Using CST Microwave studio, a simple design has been simulated and the working process has been documented in this paper in six sections. Section 2 covers the literature review of microstrip patch antenna for wireless communications using 5 GHz band. In Sect. 3, the design specifications and the geographical model architecture is explained, followed by Sect. 4 where the design equations used for the calculations are listed. Section 5 explains and analyses the simulated design in terms of calculated antenna characteristics, and offers a comparative study against existing works. Finally, the conclusion of the work is discussed in Sect. 6.

2 Literature Review

The first microstrip antenna was introduced in the 1950s. Its development accelerated in the early 1980s and is currently ongoing [7]. In 2012, Alam et al. [8] proposed a design of an EBG single band microstrip patch antenna for WLAN and HIPERLAN applications where various values of return loss and bandwidth were attained by varying the length of the L-type slot. Additionally, a maximum return loss of -21.69 dB has been achieved at 5.4 GHz resonant frequency by 3×3 EBG structure [8]. In 2014, Khan et al. [9] designed an microstrip slot antenna at 5.4 GHz resonance frequency for WiMAX applications that achieved -15 dB return loss. Yang et al. [10] devised miniaturized structures of two dual band microstrip antennas for WLAN communication. The monopole antenna operated in the 4.5 GHz–7.5 GHz and 4.5 GHz–7.5 GHz frequency bands, while the microstrip antenna covered the 2.4 GHz–2.46 GHz and 5.16 GHz–5.4 GHz ranges. A rectangular microstrip array antenna was designed in 2017 by Parameswari et al. [11] for 5.4 GHz Wi-Fi applications. The design achieved 15 dB, 20 dB and 40 dB reflection coefficients through the use of 1×1 , 1×2 and 2×2 array antennas, respectively. A triple-band monopole antenna was designed by Kulkarni et al. [12] in 2019 for various wireless applications where 34 dB return loss was obtained at 5.52 GHz cut-off frequency. In the next year, Vahora et al. [3] proposed a design of triple-band array antenna sporting -23.5 dB return loss with a bandwidth of 220 MHz at 5.4 GHz cut-off frequency. In 2021, Kumar et al. [13] designed a 1×2 adaptive microstrip array antenna which operated at 5.4 GHz and 2.45 GHz resonant frequencies. The return losses and the bandwidths were -15.74 dB and 60 MHz for the 2.45 GHz band, and -49.09 dB and 200 MHz for the

5.4 GHz scenario. In the same year, Thatere et al. [14] designed a modified rectangular microstrip antenna for wireless communication purposes that achieved -21.41 dB reflection coefficient and 236 MHz bandwidth at 5.302 GHz operating frequency. The existing literature indicates that there is a trade-off between gain and bandwidth. Additionally, designs tend to get more complex and bigger in size to improve return loss. This paper strives to balance the conflicting parameters, improving return loss in particular, while offering a simpler approach.

3 Design and Modelling

To make the antenna suitable for the wireless applications at 5.4 GHz an appropriate measurement has been chosen first. Then the antenna has been designed in CST STUDIO SUITE software based on that measurement. Copper (Cu) material has been used to construct both ground and patch layer of the antenna. Each of these layers contain a thickness of 0.03 mm. Apart from this, 1 mm thick FR-4 material has been used to construct the substrate layer of the antenna. The reason for choosing Copper (annealed) and FR-4 (lossy) materials inside the software is to make the design realistic, as no materials are completely pure.

The geometrical architecture of the antenna is shown in the figure given below. Figure 1 (a) shows the frontal geometrical architecture of the antenna in free space of the software window. The (c) and (d) marked portion of Fig. 1 (a). represents the slots cut and transmission line or feeding line of the designed antenna respectively. Those two slots at the lower portion of the patch layer have a width of 0.075 mm, and transmission line has a width of 0.775 mm only. The Fig. 1 (b) shows the layers of the designed antenna and its specification. The view of the antenna from the bottom is shown by Fig. 2 (a). Line feeding technique has been used and the antenna is fed via the port that is portrayed by a red region denoted by the number “1”.

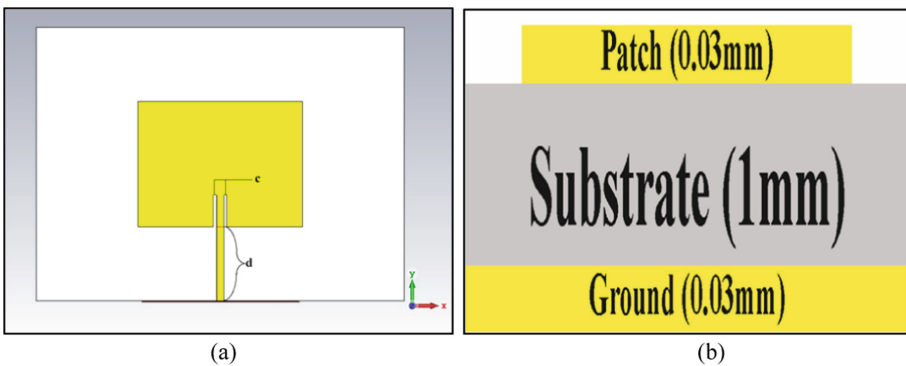


Fig. 1. Design Specification: (a) feeding line and slots of the antenna, and (b) layers of the antenna

Figure 2 (b) depicts the antenna from a 3D viewpoint. The perspective view of the antenna in X-Y-Z plane in free space of CST software window is shown.

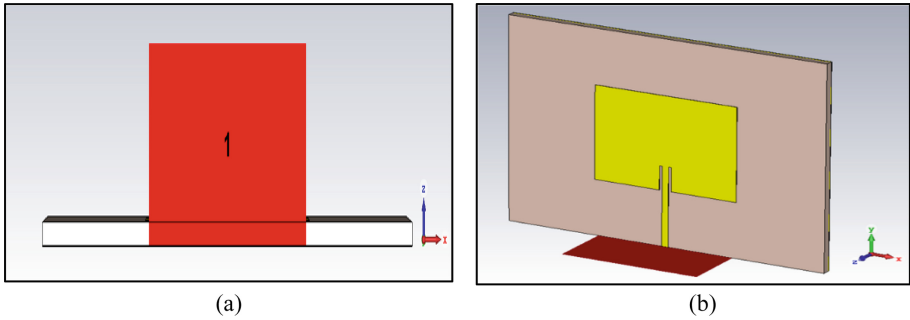


Fig. 2. (a) Bottom view, and (b) Perspective view of the Antenna in X-Y-Z plane

Table 1 lists the parameters that were specified in the software to simulate the antenna. The total dimension of the antenna is $38 \times 28 \times 1.06 \text{ mm}^3$ whereas the patch layer dimension is $17 \times 12.8 \times 0.03 \text{ mm}^3$.

Table 1. Design Specifications

Representation	W_g	L_g	H_G or H_P	H_S
Value (mm)	38	28	0.03	1
Specification	Ground Width	Ground Length	Ground & Patch Height	Substrate Height
Representation	W_p	L_p	W_f	INS_w
Value (mm)	17	12.8	0.775	0.075
Specification	Patch Width	Patch Length	Transmission Line Width	Width of Insert (lower slot)

4 Design Equations

Formulas that have been used in this work are listed in the following table (Table 2) [3].

Table 2. Used formula

Calculation of the Width of patch (W)	$w = \frac{c}{2f_0 \sqrt{\frac{\epsilon_r + 1}{2}}}$ <p>Here, c = free space velocity of light = 3×10^8 m/s; r = the relative permittivity of dielectric substrate = 4.3; f_0 = resonant frequency = 5.4 GHz</p>
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(continued)

Table 2. (continued)

Calculation of actual length of patch (L)	$L = \frac{C}{2f_0\sqrt{\frac{\epsilon_r+1}{2}}} - 0.824h \left\{ \frac{(\epsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\epsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \right\}$ <p>Here, h = substrate's height, w = patch's width, ϵ_{reff} = effective dielectric constant</p>
Calculation of Effective dielectric constant (ϵ_{reff})	$\epsilon_{reff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2} \left[\frac{1+12h}{w} \right]^{0.5}$
Inset feed depth determination (y_0)	$y_0 = \frac{\left\{ \cos^{-2}\left(\frac{z_0}{R_{in}}\right)L \right\}}{\pi}$ <p>Here, z_0 = line impedance, R_{in} = input impedance, L = length of patch</p>

5 Simulation and Result Analysis

Different parameters such as S-parameter/Return Loss, Far-Field pattern, Bandwidth, Voltage Standing Wave Ratio (VSWR), Efficiency of the antenna have been analyzed after completing the simulation.

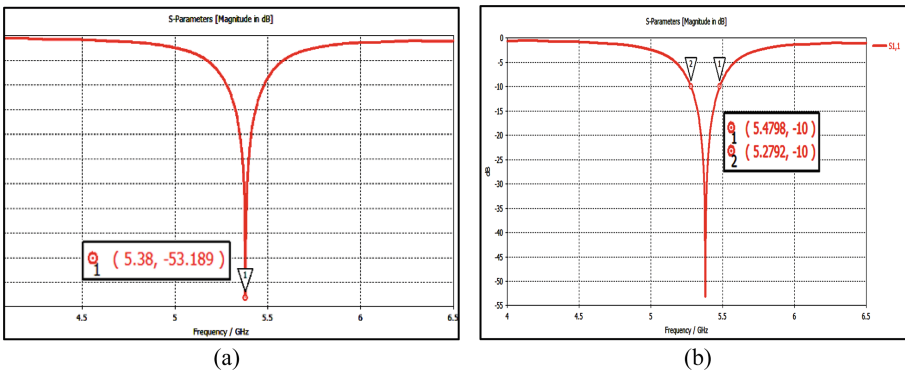


Fig. 3. (a) Antenna's S-parameter determination, and (b) Data measurement for bandwidth

Figure 3 (a) depicts the s-parameter S_{11} of the antenna at resonant frequency. At 5.38 GHz the return loss of the antenna is found to be 53.189 dB. Figure 3 (b) illustrates the necessary information to calculate the bandwidth of the frequency band. Depending on the information provided by the above figure, the calculated bandwidth = upper cutoff frequency – lower cutoff frequency = (5.4798 – 5.2792) GHz = 0.2006 GHz = 200.6 MHz, which is adequate for WLAN application.

Figure 4 (a) indicates the Three Dimensional (3D) Far-Field pattern of the antenna. The figure illustrates the radiation efficiency and the total efficiency of the antenna. Both the radiation efficiency and total efficiency of the antenna at resonant frequency are 3.632 dB, and the directivity is 6.156 dBi. Figure 4 (b) shows the polar Far-Field pattern of the antenna, and also depicts that the major beam of the antenna has a magnitude of 6.16 dBi. It also illustrates that the antenna’s main beam has an angular width of 97.9° that is pointing at 3°.

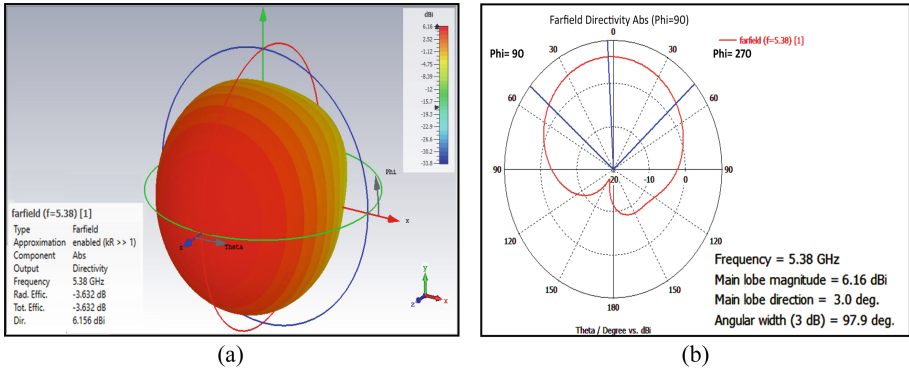


Fig. 4. (a) Antenna’s 3D Far-field pattern, and (b) Antenna’s polar far-field radiation pattern

The value of antenna gain is extracted from Fig. 5 (a) and is found to be 2.5817 dBi at resonant frequency. Efficiency is one of the major factors used to analyse or measure antenna efficiency, which is mostly affected by two parameters- antenna gain and directivity. Following the given formula, the efficiency of the antenna can be determined as $\frac{Gain(dBi)}{Directivity(dBi)} \times 100 = \frac{2.5817}{6.156} \times 100 = 41.938\%$.

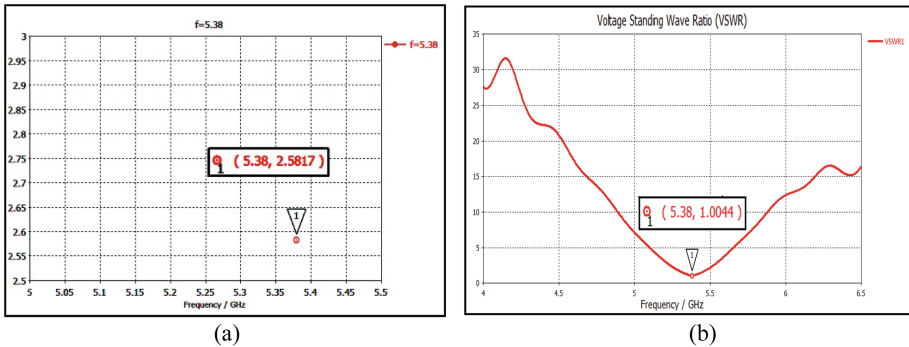


Fig. 5. (a) Antenna gain, and (b) Voltage Standing Wave Ratio (VSWR) indication

VSWR is one of the main factors in antenna design. VSWR, which is assumed to be a generally acceptable margin, has a value of between zero and two. Here the value of

VSWR of the designed antenna almost tends to 1 at resonant frequency that is illustrated by Fig. 5 (b).

Various antenna parameters such as return loss and resonance frequency were analyzed in this paper using data from previous research papers. In comparison to the references in Table 3, a better return loss was obtained at the operating frequency of 5.38 GHz from the CST simulation of the suggested design. So, the proposed design performs better in that perspective. The bandwidth is also adequate for WLAN application.

Table 3. Comparative Study

Resonance frequency (GHz)	$S_{1,1}$ (dB)	Bandwidth (MHz)	Ref.
5.4	-17.04	230	[8]
5.4	-15	-	[9]
5.2	-24.5	240	[10]
5.4(Single patch antenna)	-10	-	[11]
5.4(1×2 array antenna)	-20	-	[11]
5.4(2×2 array antenna)	-40	-	[11]
5.52	-34	-	[12]
5.4	-23.5	220	[3]
5.45(Single patch antenna)	-47.59	240	[13]
5.45(1×2 array antenna)	-49.097	200	[13]
5.284	-19.778	239.3	[14]
5.302	-21.41	236.7	[14]
5.38	-53.189	200.6	This work

6 Conclusion

A rectangular microstrip patch antenna with a size of $38 \times 28 \text{ mm}^2$ has been successfully simulated and designed on a substrate with a dielectric constant of 4.3 using CST software in this paper. This project aims to achieve the desired results by maintaining the antenna design simple, keeping in mind the challenges faced in fabrication. Several considerations were taken into account for improving the efficiency of the antenna, including operating frequency, measurements, and substrate selection. This designed antenna is proposed for WLAN applications that operate in the 5.38 GHz frequency range. This antenna followed the WLAN communication standards with a bandwidth of 200.6 MHz in the frequency spectrum of 5.4798 to 5.2792 GHz. The return loss value of 53.189 dB, higher than the values found in existing literature, indicates that the impedance matching is excellent. This antenna achieved an efficiency of 41.938% with a VSWR of 1.0044. A section of this paper shows a comparison between the results of previous research papers featuring antennas designed for WLAN applications, and

the results of the proposed antenna design are also discussed. The comparative analysis shows that the designed antenna has been able to achieve better return loss with adequate bandwidth. The results also indicate that the proposed antenna can be used successfully for WLAN communication.

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