

Design of High Performance Dual-band Microstrip Patch Antenna for Wi-Fi Applications

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Abstract

Micro strip antennas are low-profile occupies less space and requires less power. A metal patch mounted at a ground level with a di-electric material in-between constitutes a Micro strip or Patch Antenna. In this paper, it is proposed to design a Microstrip patch antenna operating at 2.4 GHz and 5.8 GHz frequencies. The primary aim is to create a compact, easily fabricated, and high-performance antenna. It is proposed to incorporate a copper patch with strategically placed slots on an FR-4 substrate, along with a 50Ω microstrip feed line. In this paper, it is proposed to measure the VSWR, Return loss, Directivity and radiation pattern of the proposed antenna. It is proposed to design this antenna using CST Microwave studio software.

Keywords:

Microstrip Patch Antenna, Wi-Fi, Dual-Band, 2.4/5.8 GHz, CST Simulation

1. INTRODUCTION

In today's world of wireless communication, antennas that can handle different frequencies are crucial, especially for various applications like Wi-Fi. Wi-Fi has become ubiquitous, from our homes to cafes to offices, and having antennas that can efficiently work with Wi-Fi signals is incredibly important. One popular type of antenna for Wi-Fi is the microstrip patch antenna. These antennas are small, light, easy to make, and fit well with the technology we use in modern circuit boards.

People are really interested in designing and improving microstrip patch antennas so they can work well with Wi-Fi and other frequencies. This is important because it means we can use the radio waves in the air more efficiently, especially in crowded Wi-Fi environments. We call antennas that can handle two different Wi-Fi frequencies "dual-band antennas." They're useful because they give us more flexibility in how we use Wi-Fi.

Making a good dual-band microstrip patch antenna for Wi-Fi involves picking the right materials, shapes, and ways of sending signals to the antenna[2]. By choosing these

things carefully, we can make antennas that work well and don't take up too much space or cost too much money. This is especially important for Wi-Fi applications where space and cost are often limited.

This paper is all about how to design and improve dual-band microstrip patch antennas, particularly for Wi-Fi. We use a step-by-step approach, using computer simulations and real-world tests to ensure our antennas work efficiently with Wi-Fi signals. Our goal is to make antennas that are small, efficient, and can handle different Wi-Fi frequencies. This way, we can make Wi-Fi connections faster, more reliable, and available in more places for everyone.

2. MICROSTRIP PATCH ANTENNA

In the realm of contemporary wireless communication systems, antennas play a pivotal role in ensuring seamless connectivity across a myriad of applications. One such antenna type that has garnered significant attention is the microstrip patch antenna. The microstrip patch antenna is a popular choice due to its compact size, lightweight nature, ease of fabrication, and compatibility with modern printed circuit board (PCB) technology. These antennas consist of a radiating patch on one side of a dielectric substrate, typically backed by a ground plane on the other side. The radiating patch is usually made of conductive material such as copper and is designed to resonate at the desired frequency or frequencies.

Microstrip patch antennas offer several advantages, making them suitable for a wide range of wireless communication applications. Firstly, their compact size makes them ideal for integration into small devices where space is limited, such as smartphones, tablets, and wearable electronics. Additionally, their low profile and planar structure make them easy to manufacture using standard PCB fabrication techniques, resulting in cost-effective solutions for mass production. Moreover, microstrip patch antennas exhibit relatively high efficiency and can be designed to achieve directional radiation patterns, offering improved signal coverage and range in specific directions.^{[2][4]}

One of the key features of microstrip patch antennas is their versatility in design, which allows for the exploration of various patch shapes to achieve desired performance characteristics. Different patch shapes, such as rectangular, circular, and triangular, can be utilized to tailor the antenna's impedance bandwidth, radiation pattern, and polarization properties. Each shape offers unique advantages and trade-offs, depending on the specific requirements of the application.

Among the various patch shapes, the square patch antenna stands out as a popular choice due to its simplicity, ease of fabrication, and favorable radiation characteristics. The square patch antenna offers symmetrical radiation patterns with well-defined beam shapes, making it suitable for applications requiring uniform coverage in all directions. Additionally, the square patch geometry facilitates straightforward feeding techniques, simplifying the antenna design process and reducing implementation complexity.^[1]

The square patch antenna exhibits a fundamental resonance mode, typically corresponding to the length of one side of the square patch, as well as higher-order modes that can further enhance the antenna's bandwidth and performance. By carefully adjusting the dimensions of the square patch and the substrate material properties, designers can achieve dual-band or even multiband operation to support multiple frequency bands within a single compact antenna structure.

Furthermore, advancements in antenna design techniques, such as impedance matching networks, aperture-coupled feeding, and stacked patch configurations, have further expanded the capabilities of square patch antennas, enabling enhanced performance and versatility in diverse wireless communication systems [6][1]. With ongoing research and innovation, the square patch antenna continues to be a compelling choice for applications ranging from mobile communications and Wi-Fi networks to satellite communication and radar systems.

3. DESIGN EQUATIONS

STEP 1: Calculation of Patch Width (w)

$$w = \frac{c}{2f_0\sqrt{\frac{\epsilon_R+1}{2}}} \quad (3.1)[1]$$

STEP 2: Calculation of Effective Dielectric Constant

$$\epsilon_{eff} = \frac{\epsilon_R+1}{2} + \frac{\epsilon_R-1}{2} \left[1 + 12 \left(\frac{h}{w} \right) \right]^{-1/2} \quad (3.2)$$

STEP 3: Calculation of Actual Length of Patch(L)

$$L = l_{eff} - 2\Delta l \quad (3.3)$$

$$l_{eff} = \frac{c}{2f_0\sqrt{\epsilon_{eff}}} \quad (3.4)$$

$$\Delta l = 0.412h \frac{(\epsilon_{eff} + 0.3) \left(\frac{w}{h} + 0.265 \right)}{(\epsilon_{eff} - 0.258) \left(\frac{w}{h} + 0.8 \right)} \quad (3.5)$$

STEP 4: Calculation of Substrate Width and Length^[2]

$$L_s = 6h + L \quad (3.6)$$

$$W_s = 6h + w \quad (3.7)$$

Where ,

C = Speed of Light

f_0 = Resonant frequency

ϵ_R = Dielectric constant

h = height of the substrate

w = Patch Width

Δl = fractional length

l_{eff} = effective length

Applying the designated formulas facilitates the extraction of fundamental design metrics crucial for refining antenna performance. Through rigorous refinement utilizing Computer Simulation Technology (CST), an advanced electromagnetic simulation tool, these metrics undergo meticulous optimization. The resulting optimized values are systematically cataloged and presented in a tabular format, serving as a tangible manifestation of the exhaustive endeavors dedicated to the design process. This comprehensive approach ensures that each aspect of the antenna's performance is thoroughly examined and refined to achieve optimal functionality. The 1D representation of top view and bottom view of designed antenna along with the parameters table is as follows:

TABLE I: OPTIMIZED DESIGN METRICS

Name of Parameter	Optimized Value (in mm)
Length of Substrate(L_s)	50
Width of substrate(W_s)	50
Length of Patch(L_p)	25
Width of Patch(W_p)	25
Length of Feedline (L_f)	14
Width of Feedline (W_f)	0.5
Length of Slot1 (L_{s1})	9.7
Length of Slot2(L_{s2})	4
Length of Slot3(L_{s3})	4
Width of Slot1(W_{s1})	2.5
Width of Slot2(W_{s2})	1.6

Width of Slot3(W_{s3})	1.6
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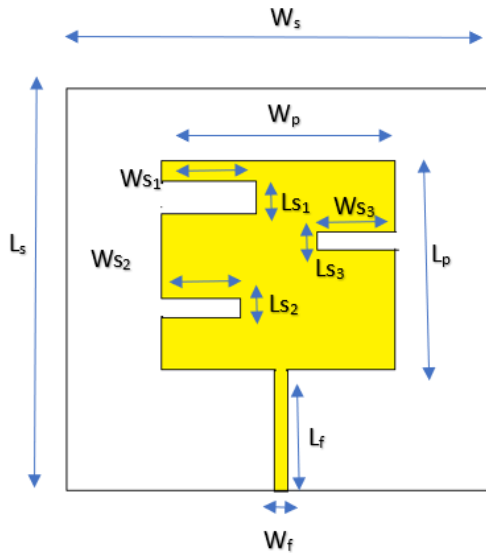


Figure 1. Front view of Dual-Band Microstrip Patch Antenna

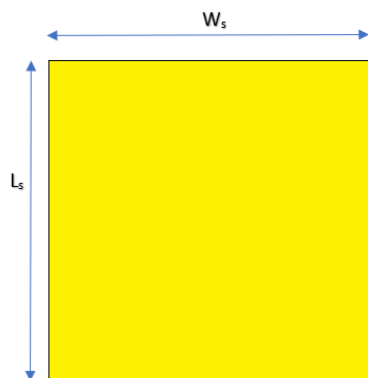


Figure 2. Back View of Dual-Band Microstrip Patch Antenna

4.DESIGN OF DUAL-BAND PATCH ANTENNA

This section elaborates on the design architecture of the dual-band microstrip patch antenna. The design process is initiated based on the metrics obtained from Table-1, which serve as crucial guidelines for crafting an optimized antenna configuration. Leveraging the capabilities of Computer Simulation Technology (CST), the antenna design is meticulously formulated, incorporating precise dimensions and parameters to ensure optimal performance. Figures 3 and 4 provide detailed front and rear views of the antenna design, visually depicting the intricate layout and configuration achieved through CST simulation. These visual

representations offer valuable insights into the structural aspects and geometrical intricacies of the designed antenna.

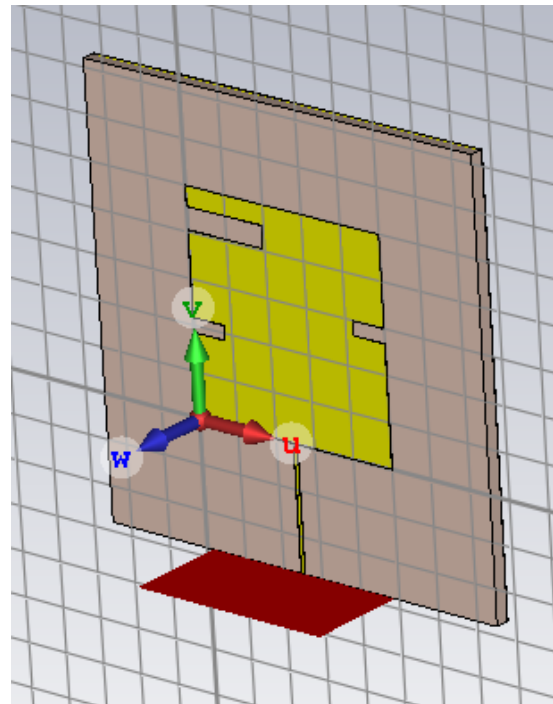


Figure 3. Front View of Dual-Band Microstrip Patch Antenna

In Figure 3, the front view of the dual-band antenna is presented, where the axes u , v and w correspond to the x , y and z coordinates respectively. Furthermore, the illustration highlights the antenna's placement on the x - y plane, with its orientation perpendicular to the z -axis. This deliberate positioning is aimed at optimizing radiation in the z -direction, ensuring maximum efficiency and performance for the antenna's intended functions [9][7][1]. The detailed visualization provided in Figure 3 offers valuable insights into the spatial arrangement and alignment of the antenna, providing a comprehensive understanding of its operational dynamics.

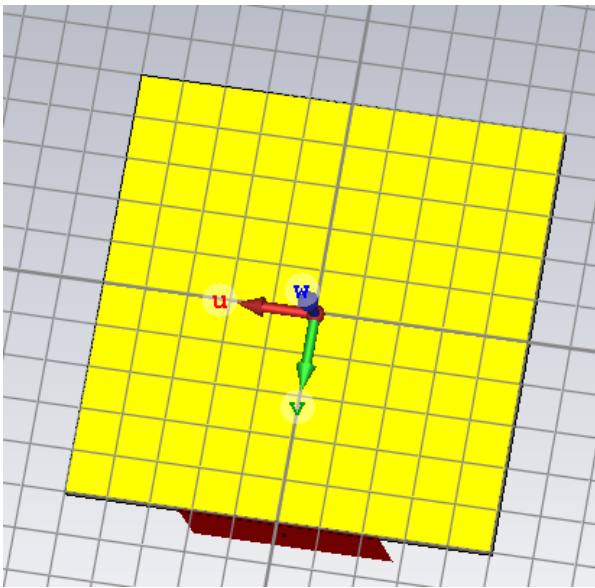


Figure 4. Back View of Dual-Band Microstrip Patch Antenna

The figure referenced above, Figure 4, presents a panoramic depiction of the entire ground structure from a perspective angle. Notably, it accentuates the port, prominently showcased as the rectangular structure within the visualization. It's paramount to recognize that the exhaustive design composition, encapsulating all essential components, is comprehensively delineated across Figures 3 and 4. Together, these visual representations offer an intricate portrayal of the antenna's architectural intricacies, furnishing invaluable insights into its holistic design configuration and spatial orientation.

At its core, the design is predominantly composed of two distinct materials: copper, which serves as the primary conducting material, and FR-4, utilized as the dielectric material. Copper, prized for its exceptional electrical conductivity, is strategically employed to form the antenna's radiating elements and feed structures [9][3]. This choice ensures efficient transmission and reception of electromagnetic signals, optimizing the antenna's performance. Conversely, FR-4, a ubiquitous substrate material renowned for its dielectric properties, provides essential support and insulation. Its inclusion ensures the structural integrity and stability of the antenna while maintaining optimal signal propagation characteristics. This deliberate selection of materials underscores the meticulous consideration given to electrical performance, mechanical durability, and manufacturability in the antenna's design and construction.

5. PERFORMANCE EVALUATION

This section provides an exhaustive examination of the results obtained through CST simulations, centering on parameters crucial to understanding return loss, notably S-parameters, Voltage Standing Wave Ratio (VSWR), and far-field radiation plots. S-parameters stand as foundational elements in microwave engineering, serving to delineate the intricate behavior of linear electrical networks. They encapsulate the intricate relationship between incident and reflected waves at each port of the network, offering profound insights into signal transmission and reflection dynamics. Complementing S-parameters, VSWR emerges as a pivotal metric derived from these parameters, offering a quantifiable measure of power transfer efficiency between the antenna and transmission line. It delineates the ratio of maximum voltage to minimum voltage along the transmission line, thereby serving as a litmus test for impedance matching and signal fidelity. Concurrently, return loss, expressed typically in decibels (dB), emerges as a fundamental gauge of antenna performance, gauging the magnitude of reflected power in relation to incident power at the antenna port. Its significance lies in its ability to signify impedance matching quality, with lower return loss values indicating superior efficiency and enhanced impedance matching [4]. Recognizing the interplay between these parameters underscores the intricate symbiosis between antenna design, electrical performance, and signal propagation. Through meticulous analysis of these outcomes and their respective thresholds, engineers can iteratively refine antenna designs to attain optimal performance while adhering to stringent design specifications and performance criteria. Moreover, the inclusion of far-field radiation plots offers a visual representation of the antenna's radiation pattern, offering critical insights into its directional characteristics and coverage area. This comprehensive assessment of results not only provides a thorough evaluation of the antenna's performance but also serves as a guiding beacon for further optimization endeavors aimed at meeting and surpassing desired specifications and operational requirements.

S-PARAMETER RESULTS:

The figure denoted as Figure 5 illustrates the S-parameter plot, notably emphasizing the S11 values at two distinct frequencies, namely 2.4GHz and 5.8GHz. At these frequencies, the S11 values are recorded as -18.556 dB and -38.482 dB, respectively. These values are indicative of the level of return loss experienced by the antenna at each frequency, reflecting the magnitude of power reflected back from the antenna port relative to the incident power. A lower S11 value signifies better impedance matching and reduced signal reflection, thus indicating enhanced antenna performance [5][1]. By highlighting these significant S11 values, Figure 5 provides critical insights into the antenna's impedance characteristics and validates its suitability for operation at the specified frequencies.

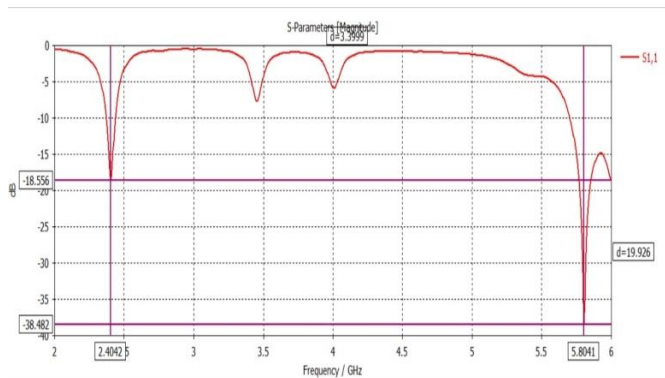


Figure 5. S11 Parameter plot with respect to frequency.

VSWR RESULTS:

Figure 6 showcases the VSWR plot, drawing attention to the VSWR values at two distinct frequencies: 2.4GHz and 5.8GHz. At these frequencies, the VSWR values are notably recorded as 1.0215 and 1.2656, respectively. These values serve as crucial indicators of the efficiency of power transfer between the antenna and transmission line. A VSWR value close to 1 signifies optimal impedance matching and minimal signal reflection, while higher values suggest impedance mismatches and potential signal loss. The significance of these VSWR values lies in their ability to validate the antenna's performance and suitability for operation at the specified frequencies, ensuring robust signal transmission and reception capabilities. [8][1]

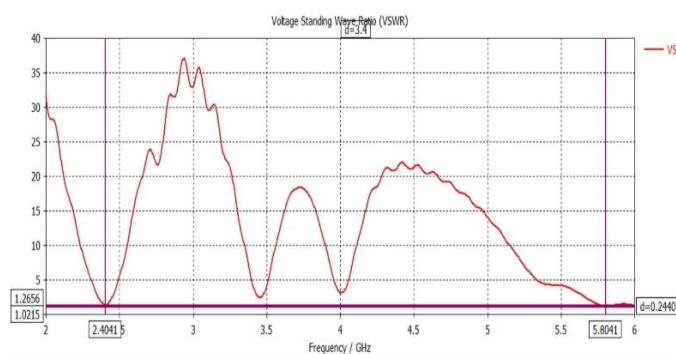


Figure 6. VSWR Parameter plot with respect to frequency

FAR-FIELD RESULTS:

The far-field parameters of an antenna play a pivotal role in comprehensively assessing its radiation characteristics and coverage capabilities. These parameters, often depicted through far-field radiation plots, offer invaluable insights into the antenna's directional properties and the spatial distribution of electromagnetic energy. Through meticulous analysis of

far-field radiation patterns, engineers gain a deep understanding of crucial factors such as beamwidth, directivity, which is paramount for evaluating the antenna's performance in transmitting and receiving signals across a designated area. [6][4] Furthermore, far-field parameters facilitate the assessment of signal propagation, coverage range, and interference mitigation, thereby guiding the optimization of antenna designs to meet the diverse requirements of modern communication systems. By leveraging this wealth of information, engineers can ensure the development of antennas that deliver reliable and efficient wireless connectivity across a spectrum of applications.

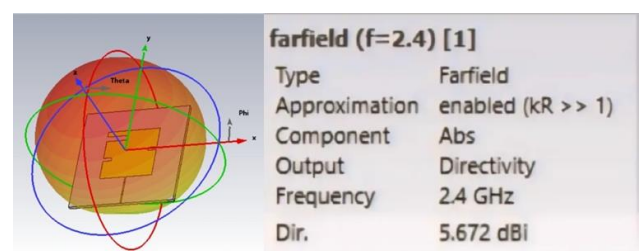


Figure 7. 3D Far-Field Plot at 2.4GHz (along with the radiation efficiency, total efficiency and directivity achieved at that particular frequency)

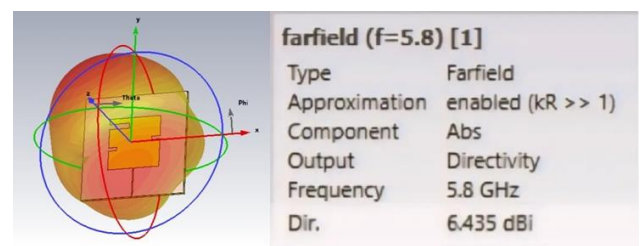


Figure 8. 3D Far-Field Plot at 5.8GHz (along with the radiation efficiency, total efficiency and directivity achieved at that particular frequency)

Illustrated in Figure 7 is the far-field plot, presenting a comprehensive depiction of the far-field radiation pattern specifically at 2.4GHz along with the radiation efficiency, total efficiency and directivity achieved at that particular frequency. Similarly, Figure 8 depicts the radiation pattern specifically at 5.8GHz along with the radiation efficiency, total efficiency and directivity achieved at that particular frequency. What sets

this visualization apart is the use of a color scale to represent the intensity of radiation, offering a nuanced understanding of the antenna's radiation characteristics. This intricate visualization enables engineers to discern not only the spatial distribution but also the strength of electromagnetic radiation emitted by the antenna within the far-field region. By closely analyzing the far-field plot, engineers can glean valuable insights into the antenna's directional properties, coverage area, and radiation efficiency at the designated frequency. Such in-depth analysis serves as a crucial tool in optimizing antenna performance, ensuring robust and reliable signal transmission and reception across a diverse array of communication scenarios.

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6. CONCLUSION

In conclusion, the dual-band microstrip patch antenna, featuring a rectangular conductive patch with three slots, effectively operates at both 2.4 GHz and 5.8 GHz frequencies, meeting IEEE 802.11 standards. Simulation results confirm satisfactory S11 parameters and VSWR performance. Its compact design facilitates easy fabrication and seamless integration into various systems, making it a practical choice for Wi-Fi applications, ensuring reliable connectivity with minimal complexity.

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