

Design And Performance Analysis Of Rectangular Microstrip Patch Antenna

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Abstract: The design and fabrication of a rectangular microstrip patch antenna using the ADS-Momentum software are presented. By design, the antenna resonates at 4.1 GHz, which makes it suitable for modern wireless communication applications. From simulation results, the reflection coefficient below -10 dB was observed within the wide frequency band from 3.1 GHz to 5.1 GHz, confirming stable and efficient operation within this spectrum. The antenna is realized on the Glass Epoxy (FR4) substrate with a dielectric constant of $\epsilon_r = 4.4$ and a loss tangent of $\tan \delta = 0.02$, providing a low-cost and reliable platform for fabrication. The optimized patch is excited using a microstrip transmission line feed. Its length and width are optimized to result in proper impedance matching and enhanced performance. Performance metrics such as gain, S-parameters, directivity, and efficiency of the proposed antenna are analyzed using the ADS-Momentum electromagnetic simulation tool. The radiation characteristics of the proposed antenna prove to be fairly satisfactory for broadband communication systems. The results prove the capability of ADS-Momentum to model and analyze microstrip antennas accurately, as well as the feasibility of using FR4 substrates for practical antenna fabrication. Therefore, the wide operating bandwidth combined with acceptable gain and efficiency suggests that the proposed design can be effectively deployed in WLANs, Wi-Fi, and other wireless communication systems operating within the frequency range of 3–5 GHz.

Keywords: Ultra-Wide Band, Microstrip, rectangular patch antenna, bandwidth, Return Loss, ADS Momentum.

1. INTRODUCTION

The Federal Communication Commission (FCC) has imposed some rules on UWB communication systems. Under these regulations, UWB communication is permitted in the 3.1-5.1 GHz band with a -41.3 dBm/MHz power spectral density (PSD). Radar systems are found in various applications, including surveillance and remote sensing. Radar Remote sensing techniques have been the focus of many workers. The short duration pulses sent by the ultra-wideband radar system are reflected from the target and received [1].

The antenna in a UWB radar system represents the key element in the transceiver chain. It is responsible for both transmitting and receiving the pulse signals. For that purpose, the antenna is designed to radiate and capture signals carrying information for further processing.

UWB microstrip antennas find their application in radar quite frequently. These structures are extensively used due to simple structure, low fabrication complexity and easy implementation in microwave circuits. The general structure of a microstrip antenna is a radiator patch printed on one side of dielectric substrate and the ground plane on the other as seen in Fig. 1. Various types of microstrip patch antennas in shapes like circular, square, triangular and semi-circular are available however the most widely used shape happens to be that of a rectangular plate [2][3].

This research paper presents the study and design of a rectangular patch antenna. It begins with the schematic model of the antenna, followed by the simulation results of the designed circuit. Finally, the paper concludes with a summary of the findings.

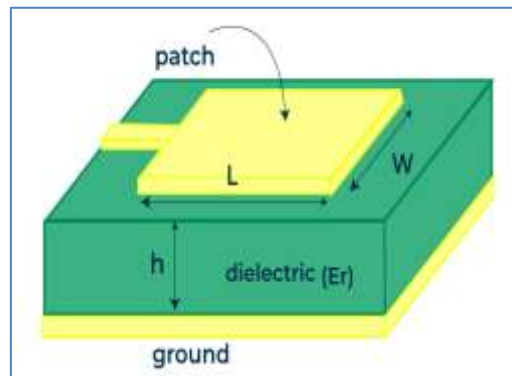


Figure 1: Rectangular Patch Antenna

1.1 Feeding Techniques of Microstrip Antenna

Patch antennas can be fed using several methods. The feeding techniques are generally divided into two main categories.

- In the contacting category, the antenna is fed through a direct connection, such as a microstrip line that is linked to the radiating patch.
- In the non-contact category, power is transferred from the microstrip line to the radiating element through electromagnetic field coupling.

The most commonly used feeding techniques for microstrip patch antennas include the coaxial probe feed, microstrip line feed, and aperture or proximity coupling methods.

A. Feeding Techniques

This mode of feeding (Fig. 2), the edge of microstrip patch is directly coupled to a conducting strip. In this method, the feed line can be etched directly on the same substrate as that of the patch to realize a planar structure. The width of the conducting strip is narrower than that of the patch.

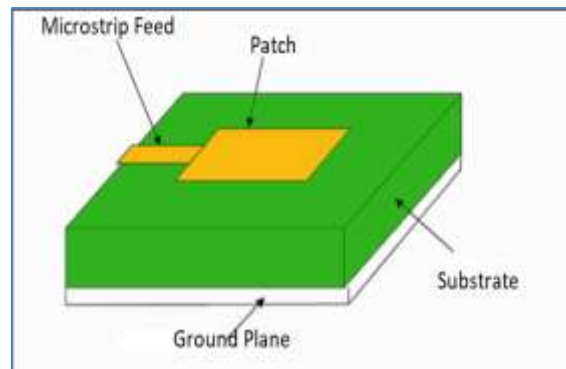


Figure 2: Microstrip line technique

B. Coaxial Probe Feeding Techniques

This feeding method, the outer conductor of the coaxial connector is connected to the ground plane, while the inner conductor passes through the dielectric and is connected to the radiating element of the antenna. However, this feeding technique has some drawbacks, such as being difficult to model and offering a relatively narrow bandwidth. Figure 3 illustrates this type of feeding method.

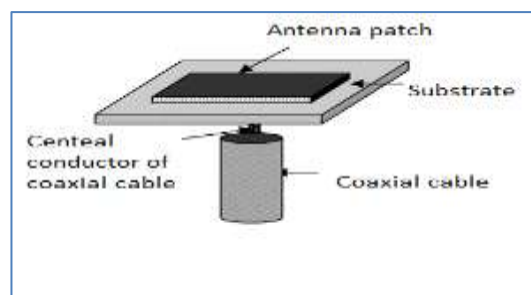


Figure 3: Coaxial probe feed

C. Feeding Techniques with proximity coupled

This feeding technique (Figure 4), two dielectric substrates are used. The feed line is placed between the two substrates, while the radiating element is positioned on the top surface of the upper substrate.

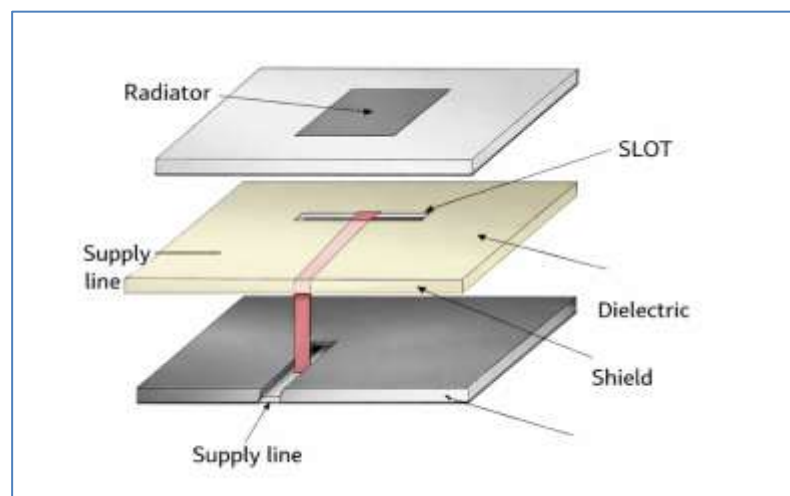


Figure 4: Proximity coupled Feed

D. Aperture coupled feed

This feeding technique (Figure. 5), the microstrip feed line is separated from the radiating patch by a ground plane. Power is transferred through an aperture or slot in the ground plane that couples the feed line and the patch. The coupling strength depends on the slot's width and length, which can be adjusted to improve bandwidth and return loss performance. The slot is typically positioned at the center beneath the radiating element [4][5].

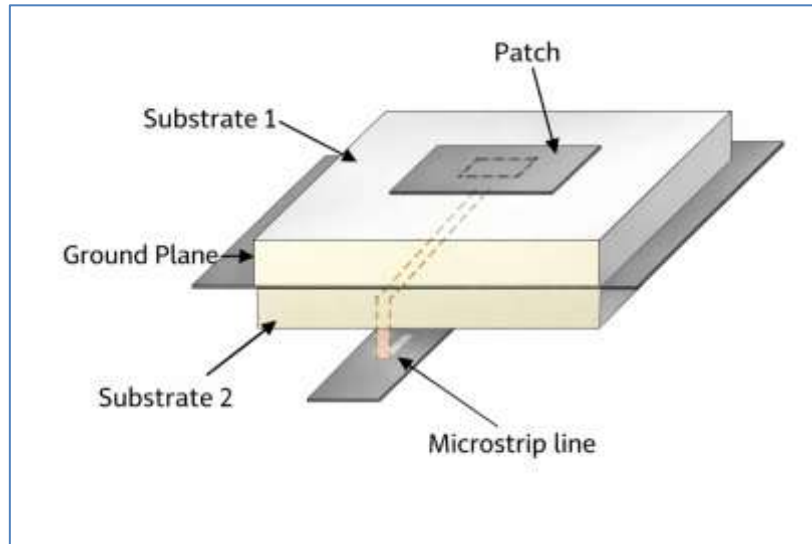


Figure 5: Aperture coupled feed

1.2 OBJECTIVES

The main objectives of the present research work are as follows

- 2 To design and develop a compact rectangular microstrip patch antenna operating in the 3–5 GHz frequency band suitable for ultra-wideband (UWB) wireless communication applications.
- 3 To optimize the antenna structure using a low-cost FR4 substrate in order to achieve wide bandwidth, good impedance matching, and improved radiation performance.
- 4 To analyze the antenna characteristics such as return loss (S11), VSWR, gain, directivity, and radiation pattern using ADS Momentum and HFSS simulation tools.
- 5 To enhance antenna performance through proper optimization of design parameters for achieving stable operation across the desired frequency band.
- 6 To validate the applicability of the proposed antenna for WLAN, Wi-Fi, and modern broadband wireless communication systems.

1.2 RESEARCH GAP

Based on an extensive review of existing literature, the following research gaps have been identified:

- 1 Most existing antenna designs either employ expensive substrate materials or involve complex geometrical structures, which increase fabrication cost and design complexity.

- 2 Several reported designs offer limited bandwidth, which does not fully satisfy the requirements of ultra-wideband communication systems.
- 3 Many studies rely on a single simulation platform, which limits the accuracy and validation of the antenna performance.
- 4 Insufficient emphasis has been given to impedance matching and return loss optimization over the complete operating band.
- 5 There is a lack of compact antenna designs that simultaneously provide low cost, wide bandwidth, acceptable gain, and stable radiation characteristics for practical wireless applications.

2. MATERIALS AND METHODS

A rectangular microstrip antenna has been designed for UWB communication applications operating at a frequency of 4.1 GHz. The proposed antenna uses an FR4 substrate with a dielectric constant (ϵ_r) of 4.4 and a substrate height (h) of 1.6 mm. This microstrip antenna operates effectively in the frequency range of 3 GHz to 5 GHz [6][7]. The main steps involved in designing a rectangular patch antenna (RPA) are as follows.

Step 1: The width of the radiating rectangular patch antenna (RPA) is calculated using the following equation:

$$W = \frac{c}{2f_r} \sqrt{\frac{2}{\epsilon_r + 1}} \quad (1)$$

Where:

c: velocity of light, 3×10^8 m/s,

ϵ_r : dielectric constant of the substrate.

f_r : resonant frequency of antenna.

Step 2: The effective dielectric constant of the rectangular patch antenna (RPA) is calculated using the following formula:

$$\epsilon_{ff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(\frac{1}{\sqrt{1 + \frac{2h}{w}}} \right) \quad (2)$$

Step 3: The effective length of the antenna is defined based on its resonance frequency.

$$L_{eff} = \frac{c}{2f_r \sqrt{\epsilon_{eff}}} \quad (3)$$

Step 4: The extension length of the rectangular patch antenna (RPA) is calculated using the following equation:

$$\Delta L = h * 0.412 * \frac{(\epsilon_{eff} + 0.3) \left(\frac{w}{h} + 0.246 \right)}{(\epsilon_{eff} - 0.248) \left(\frac{w}{h} - 0.8 \right)} \quad (4)$$

The length "L" of the PRA is calculates as:

$$L = L_{eff} - 2\Delta L \quad (5)$$

The patch dimension is $W=20.24$ mm * $L=14.85$ mm.

The feed dimension is $W_L=2.2$ mm * $L_L=8.4$ mm.

The ground plane length and width are calculated as $L_g=24.44$ mm and $W_g=29.76$ mm respectively.

The proposed rectangular patch antenna is designed using the electromagnetic simulation software ADS.

The equivalent circuit of the 4.1 GHz rectangular patch antenna in the ADS schematic is shown in Fig. 6, where:

The component M loc represents the dimensions (W and L) of the patch antenna.

The component M lin represents the feed line of the antenna.

The component M step is used to match the patch with the feed line and to enhance the bandwidth by adjusting its dimensions.

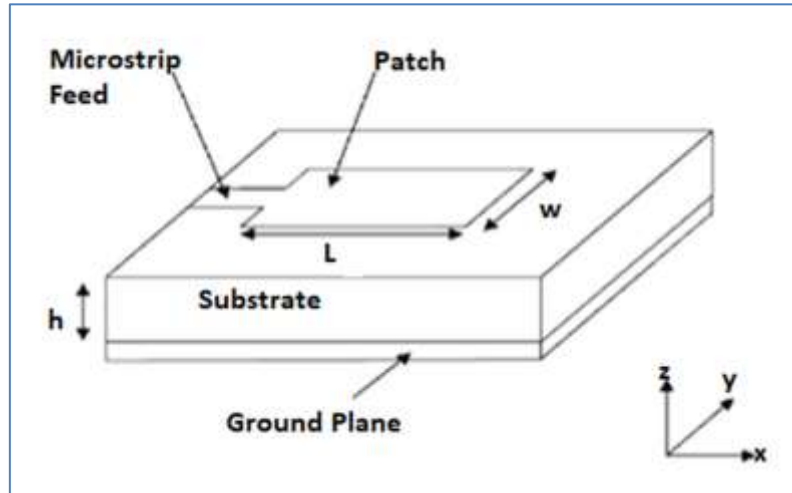


Figure 6: Schematic model of the rectangular antenna

The simulated return loss result of the rectangular antenna schematic model is shown in Figure 7.

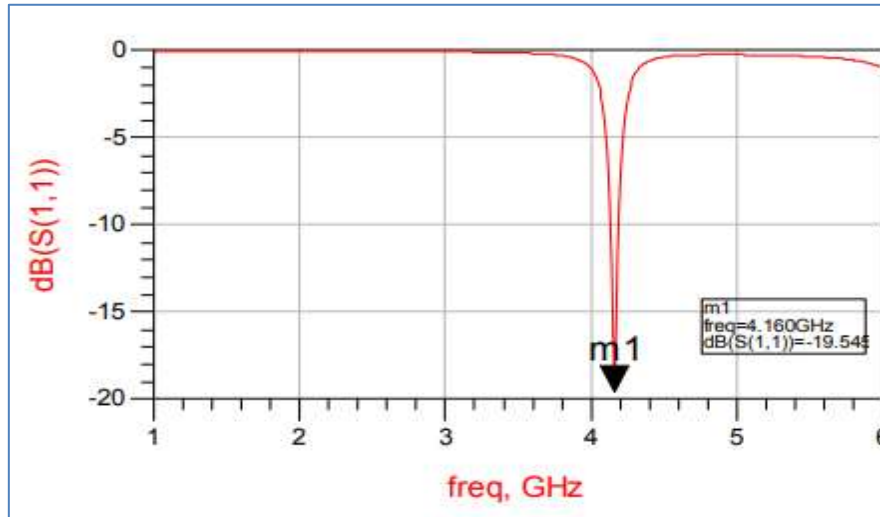


Figure7: Return loss (S11)

After simulating the rectangular patch antenna, it was observed that the bandwidth was very narrow compared to the standard UWB bandwidth of 2 GHz, which is not sufficient for proper antenna performance. To improve the design, the GOAL function in the ADS schematic was used for optimization.

To optimize the antenna circuit, the aim is to adjust the reflection coefficient (S_{11}) within the desired bandwidth. The goal is to achieve an S_{11} value of -10 dB across the frequency range of 3 to 5 GHz.

2.1 Layout Model of The Rectangular Patch Antenna

The layout window is used to create the physical design of the antenna model. The design can either be drawn directly in the layout window or first created in the schematic and then converted into a layout.

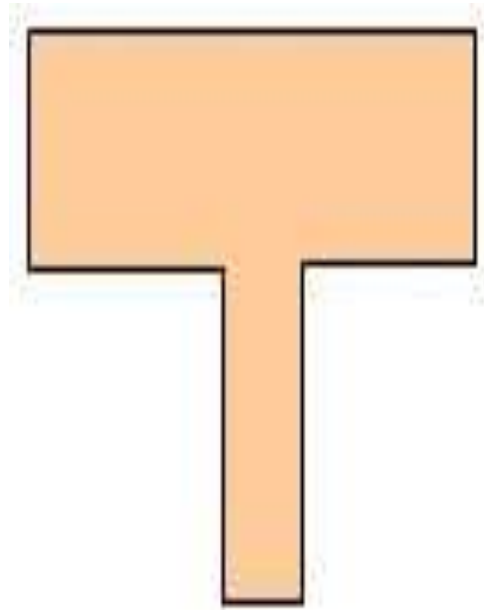


Figure8: Layout shape of the rectangular antenna

Figure 9 shows the simulated return loss (S_{11}) result of the optimized rectangular patch antenna in ADS Momentum. The figure indicates that the antenna resonates at 4.3 GHz, with a minimum return loss of -14 dB at the resonant frequency.

The radiation pattern of the UWB rectangular microstrip antenna is shown in Fig. 10. The result displays a single main lobe, which matches the expected theoretical radiation pattern of a patch antenna.

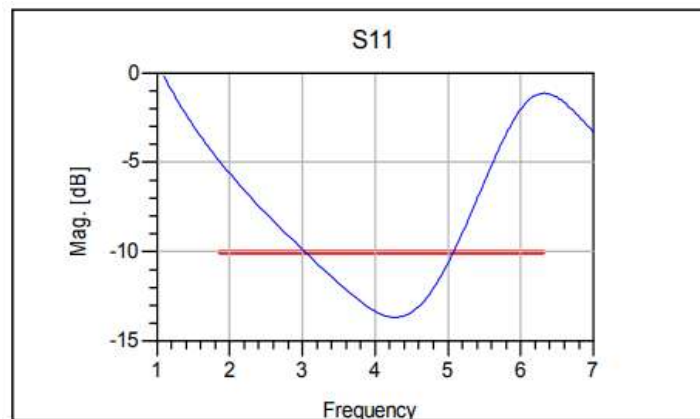


Figure 9: Return loss antenna simulation

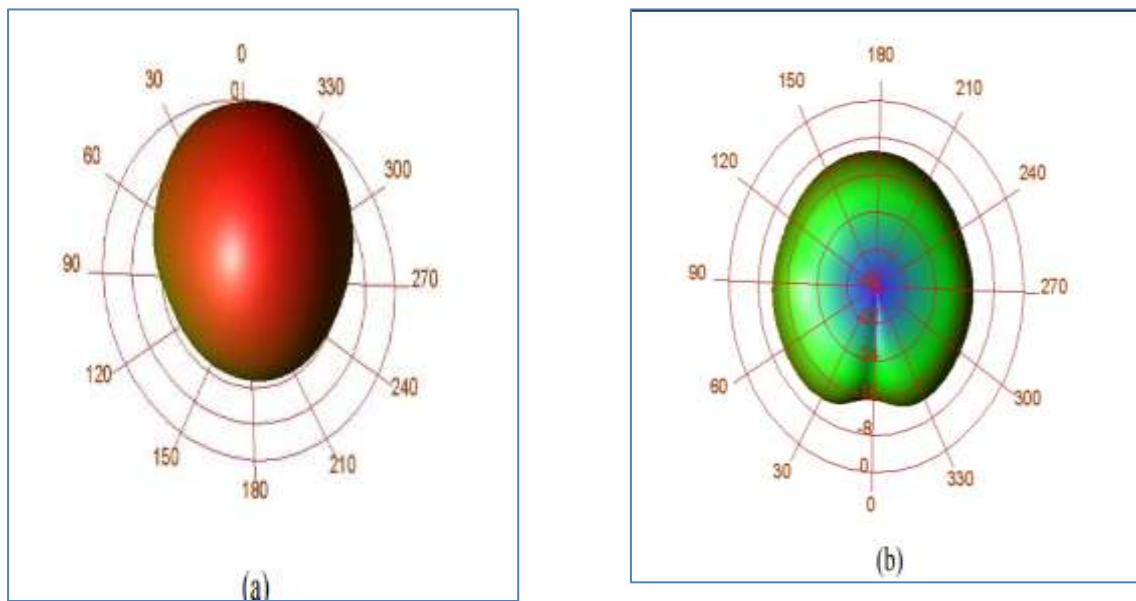


Figure 10: 3D radiation pattern: (a) Front view and (b) Opposite view

Table 1 presents the simulation results of the directivity and gain of the rectangular microstrip patch antenna. Directivity, gain, and radiated power are key parameters used to evaluate the efficiency of an antenna. A gain value of 3.48 has been obtained from the simulation.

Table 1: Antenna Parameters

Power radiated (Watts)	0.3737
Effective angle (degrees)	149.50
Directivity (dB)	5.4320
Gain (dB)	3.59
Maximum intensity (Watts/ Steradian)	0.166

2.2 Methodology Flow Chart

The methodology flow chart of the study is given below in figure 11.

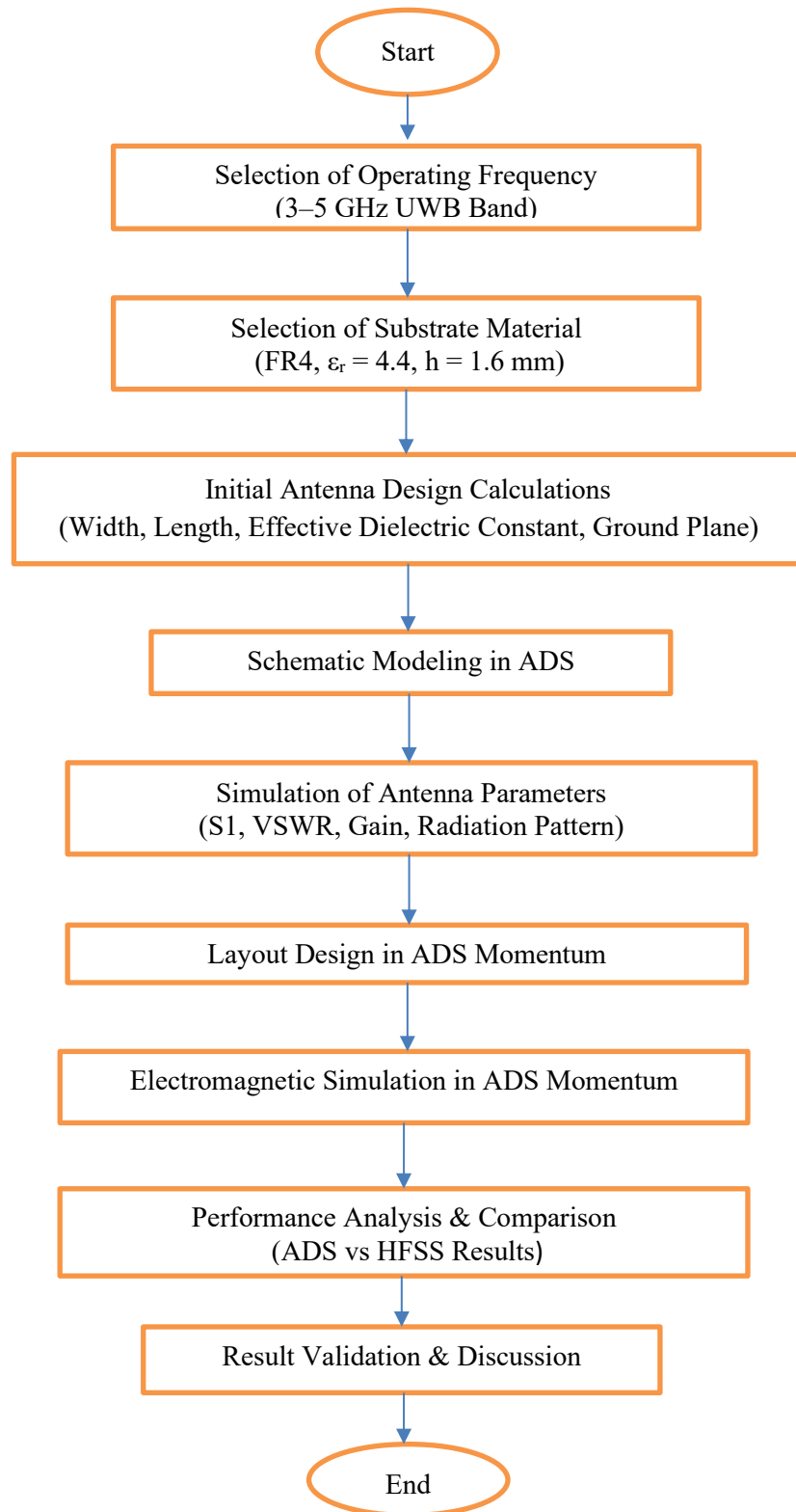


Figure 11: Methodology flow chart

3. RESULT AND DISCUSSION

The simulation results of the rectangular patch antenna obtained using Ansys High Frequency Structure Simulator (HFSS) are shown in Figure 12.

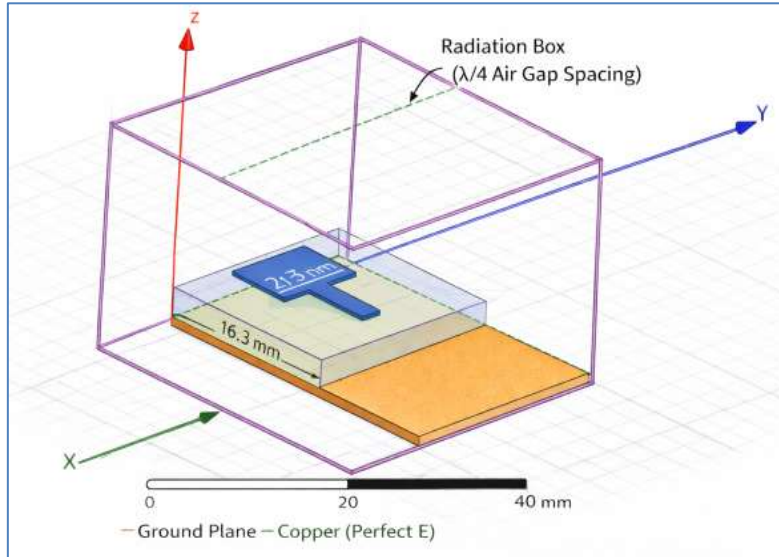


Figure12: HFSS model of microstrip antenna with rectangular patch

The HFSS simulation of the rectangular patch antenna, it was observed that the bandwidth is satisfactory compared to the standard range of 3 to 5 GHz. The antenna resonates at a frequency of 4.3 GHz, with a return loss (S_{11}) value of -30 dB.

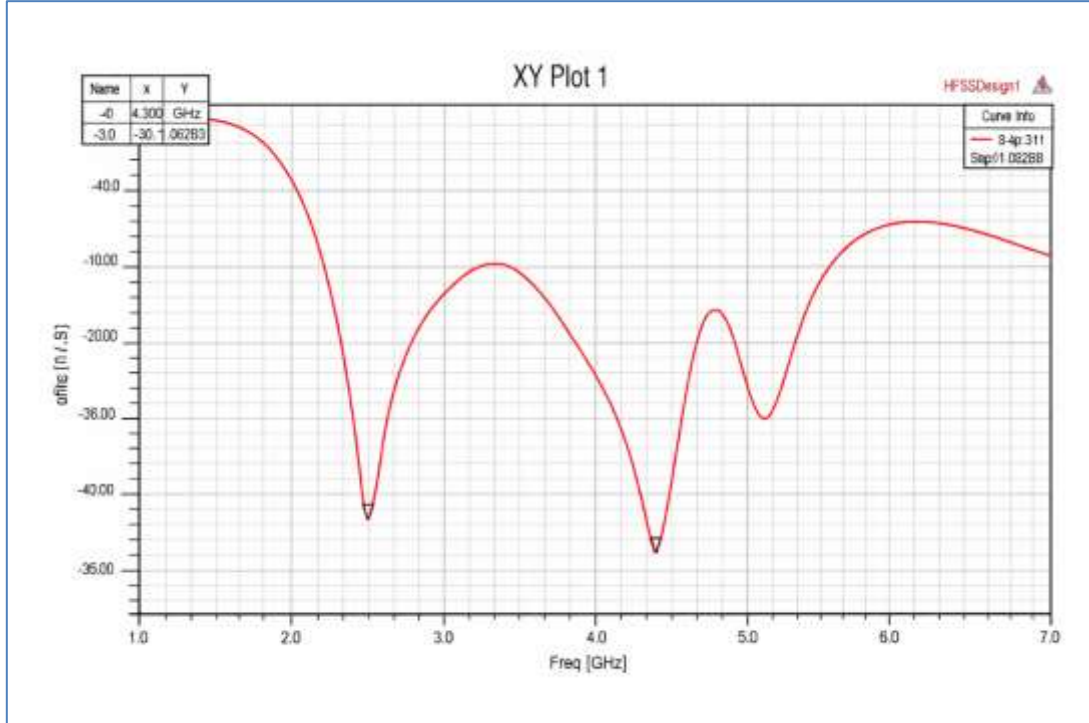


Figure13: Return loss of HFSS simulation antenna

Figure14 shows the simulated VSWR results. The VSWR value ranges between 1.6 and 1.7 across the frequency band of 3 GHz to 5 GHz.

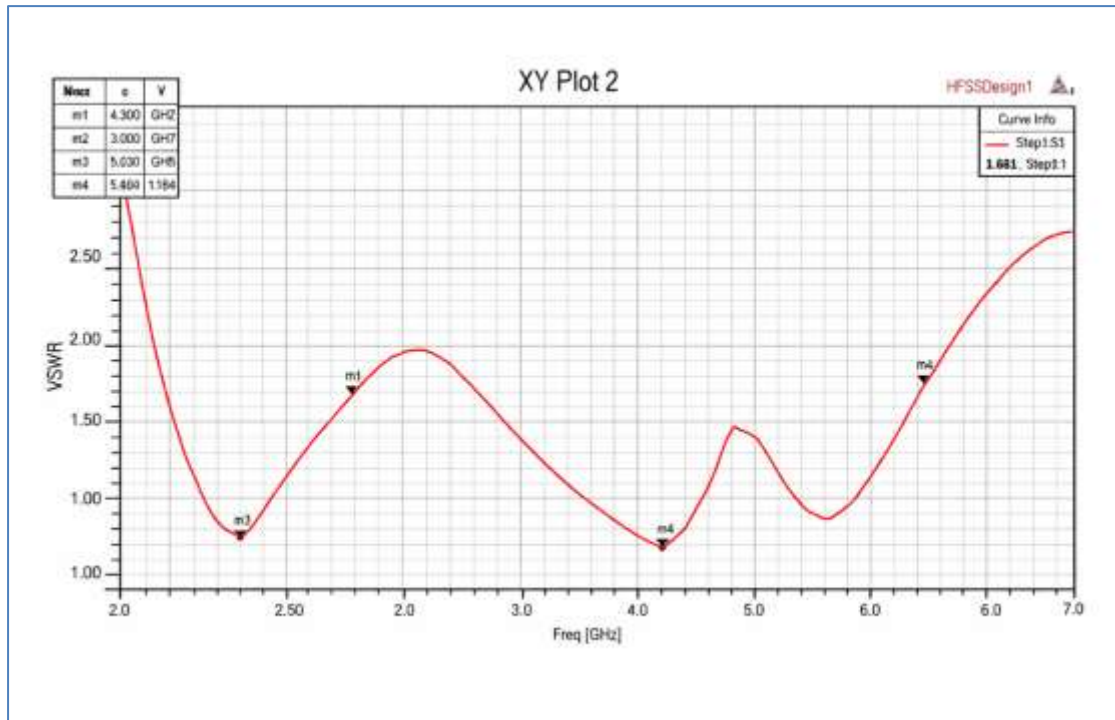


Figure 14: Voltage standing wave ratio

The difference in resonant frequency arises from the nature of the simulation software. ADS mainly focuses on planar structures, while HFSS is a more advanced tool capable of performing detailed 3D simulations.

4. CONCLUSION

This research presents the successful design and performance analysis of a compact rectangular microstrip patch antenna operating in the ultra-wideband frequency range of 3–5 GHz. The antenna was designed using a low-cost FR4 substrate, making it suitable for practical and economical wireless communication applications. The performance of the proposed antenna was analyzed using ADS Momentum and HFSS simulation tools.

The simulation results indicate good impedance matching, with return loss values below –10 dB across the operating band. The VSWR values remain within acceptable limits, ensuring efficient power transfer. The antenna also exhibits satisfactory gain, directivity, and stable radiation characteristics, which confirm its suitability for WLAN, Wi-Fi, and other broadband wireless systems. A close agreement between ADS and HFSS simulation results further validates the accuracy and reliability of the proposed design.

The designed antenna offers a balanced combination of compact size, wide bandwidth, low fabrication cost, and acceptable radiation performance. These features make it a strong candidate for modern wireless communication systems. Future work may focus on improving bandwidth, enhancing gain, and reducing antenna size through advanced design techniques such as slot loading, defected ground structures, and reconfigurable configurations.

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