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Faculty of Technology
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Design of a Frequency-Reconfigurable Antenna for 5G Applications

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Abstract*——Reconfigurable antennas are suitable for modern wireless and portable devices, as they can operate across multiple frequency bands and adjust radiation patterns based on user requirements. This paper introduces a simple frequency reconfigurable antenna. By employing frequency reconfigurability, a single antenna can accommodate various applications by switching between different bands. To enable this functionality, PIN diodes are used strategically placing these diodes within the antenna structure allows for the adjustment of the resonance frequency with minimal power consumption. The suggested antenna can function in two different frequency bands, depending on the PIN diode's switching state. It operates at 5.2GHz and 2.7 GHz during forward bias of the diode, 2.4 GHz and 2.5 GHz during reverse bias of the diode. The antenna (41×44×1.6 mm3) is designed on FR4 substrate with permittivity of 4.3 and tangential loss of 0.02 using the CST Microwave studio simulator. The resulting antenna is suitable for 5G applications .

***Keywords*—Frequency Reconfigurable Antenna, 5G Applications, PIN Diode, CST**

I. INTRODUCTION

Recent years have witnessed a notable surge in interest regarding reconfigurable antennas for use in wireless communication applications. The demand for these antennas, characterized by their high effectiveness and ease of integration into various systems, has become increasingly pressing. This importance stems from the distinctive properties these antennas possess, which include their ability to reduce signal loss, withstand high power levels, as well as their compact design and ease of integration into electronic devices [1].

A key differentiator of reconfigurable antennas apart is their unique ability to dynamically modify various antenna properties. Unlike conventional antennas, which frequently necessitate multiple antennas to accommodate various services and standards, reconfigurable antennas can meet diverse requirements using just one antenna [2].

This adaptability is achieved through the modification of the distribution or properties of the electromagnetic fields that govern their performance. Notably, advancements in frequency reconfigurability have played a crucial role in the miniaturization of antennas, facilitating their integration into small handheld devices in [3]. The realization of this reconfigurability stems from various methodologies, each contributing to the enhanced flexibility and efficiency of these antennas in wireless applications. These approaches include electrical integration using components like PIN diodes [4, 5], varactor diodes [6, 7], and Radio Frequency Micro Electro Mechanical Systems (RFMEMS) switches [8, 9]. Furthermore, structural modifications to the antenna design, such as incorporating slots and cuts [10], offer another avenue for reconfiguration. In the realm of optically reconfigurable antennas, optical switching elements, such as silicon switches [11], enable frequency modification. Finally, the exploitation of smart materials with variable properties, such as liquid crystals and ferrites [12], alongside direct physical alterations to the antenna's shape in [13], represent effective methods for achieving high functional flexibility.provided. The formatter will need to create these components, incorporating the applicable criteria that follow.

In this work, we introduce a frequency-reconfigurable antenna design that leverages PIN diodes, where the operating frequency band is determined by the diode's bias state. Specifically, a forward-biased PIN diode results in an operating frequency band of 5.2 GHz, while a reverse-biased diode shifts the operating band to 2.4 GHz. Two types of PIN diode representation were simulated and analyzed using Computer Simulation Technology (CST) software: the first is the Perfect Electric Conductor (PEC) pad method. The second type the Lumped Element Method . Each method offers a distinct approach to simulating the diode's influence on antenna performance. The PEC pad method models the diode's states through the presence or absence of metal, whereas the Lumped Element Method utilizes RLC components. We evaluate these methods to ascertain their effectiveness and accuracy in antenna design. Section II details the antenna design, including its geometry and switching techniques. Section III focuses on the simulation process and the obtained results, and Section IV provides a concise conclusion.

II. Antenna Design

The geometry of the proposed antenna is shown in Fig. 1. As illustrated, the antenna consists of three layers, each contributing to its overall performance enhancement. The first component is the ground plane with two square slots etched below the dielectric substrate, measuring 41 mm × 44 mm. The recommended substrate for the antenna is FR-4, which has a height of 1.6 mm, a relative permittivity of 4.3, and a loss tangent of 0.02. Figure 5.1(a) depicts the top view of the antenna, showing the radiating structure. The structure includes a slot cut at the upper portion of the rectangular patch, with the presence of additional slots in the antenna designed using an analytical curve in CST software. This approach allowed for precise control over the slot shapes and their placement within the antenna structure.
The PIN diodes used as switches are embedded in the L-shaped branch to attain frequency reconfiguration. By switching the operating state of the PIN diodes, the surface current distribution is changed, which alters the impedance bandwidth. When the PIN diode is switched OFF, the resonant frequency band of the antenna is 2.4 GHz and 2.5 GHz. When the PIN diode is switched ON, the resonant frequency band of the antenna is 5.2 GHz and 2.73 GHz. This antenna covers a frequency range suitable for 5G applications. The proposed antenna's parameter values are mentioned in Table 1. The antenna slots can be expressed by the equation: Y = ax + b. In our design, 'a' is set to 0.43.

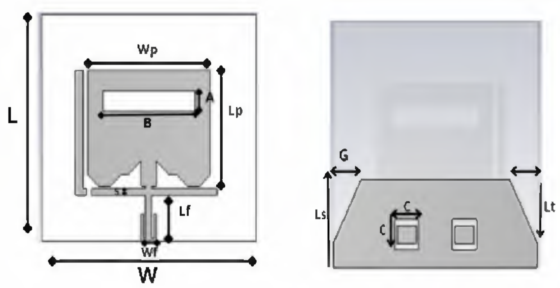


Fig. 1. The proposed antenna design: Front side in (a), and Bottom side in (b)

TABLE I. DIMENSIONS IN MM OF THE PROPOSED VA

Parameter	Value (mm)	Parameter	Value (mm)
L	44	Lp	24
W	41	Wp	21
A	18	Lf	9
B	4	L1	22.7
S	3	L2	12.3
Ls	15	Wf	3
Lt	10.5	N	4
C	5	G	5.6

III. Analysis of PIN Diode

The equivalent circuit of the PIN diode is an essential part of simulating reconfigurable antennas. This section explains the use of the PIN diode in antenna design using Computer Simulation Technology (CST) software. Two types of PIN diode representation are simulated and discussed using the lumped element and PEC pad.

A. PEC Pad

In this section, the simulation of the PIN diode is conducted using a Perfect Electric Conductor (PEC) pad, which forms the basis for its representation. To facilitate diode placement, 1mm slots are integrated into the design. as illustrated in Fig.2, the diode is modeled as either an open or a short circuit in the transmission line. The metal strip representing the PEC pad indicates the ON state of the diode, allowing the signal to pass from the port to the radiating element. The simulation results, as shown in Fig.3, indicate a return loss of -42 dB at 5.2 GHz and -24.6dB at 2.73 GHz in ON state. Conversely, the absence of the metal strip signifies the OFF state of the diode, resulting in a return loss of -37 dB at 2.4 GHz. This method offers advantages over lumped element circuits, enhancing both simulation speed and accuracy.

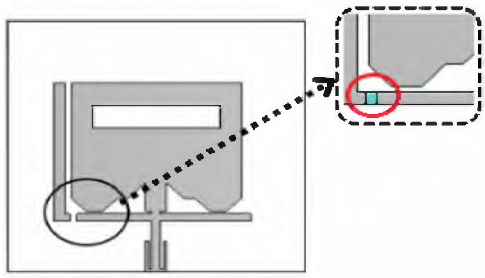


Fig. 2. The Proposed antenna while present and absent of PEC stripe.

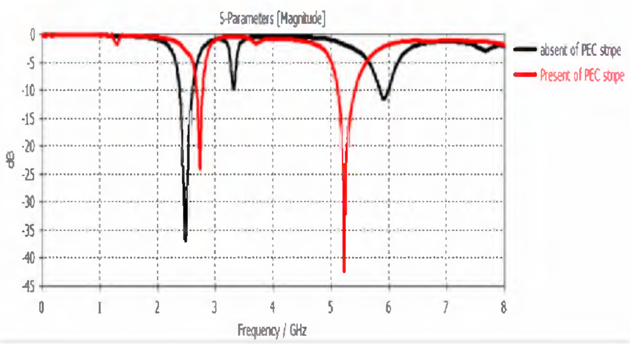


Fig. 3. Return Loss of the antenna while present and absent of PEC stripe

B. Lumped elements

Advancements in semiconductor technology have led to the prevalent use of PIN diodes in reconfigurable antennas due to their advantageous characteristics, including low insertion loss, fast switching speeds, compact size, and cost-effectiveness. This facilitates their easy integration into antenna designs, enabling frequency reconfigurability through controlled switching mechanisms.

Fig.4 illustrates the equivalent circuit of a PIN diode, which operates in two distinct modes: the ON state and the OFF state. In the ON state, the PIN diode is represented by a series connection of a resistor (Rr) and an inductor (Lf), while in the OFF state, the configuration changes to an inductor (Lf) in parallel with a resistor (R) and a capacitor (C). Functionally, in the ON state, the diode acts as a short circuit, allowing current to flow within the radiating structure, whereas in the OFF state, it obstructs current flow by behaving as an open circuit. Within the simulation environment, the PIN diode is modeled as a lumped RLC circuit. Specifically, the ON state is represented by a series combination of a 4-ohm resistance (Rr) and a 0.4 nH inductance (Lf), while the OFF state is characterized by a capacitance value of 0.07 pF.

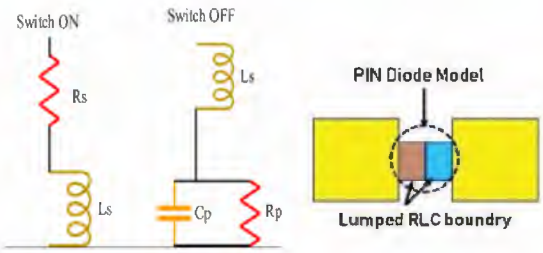


Fig. 4. Equivalent circuit of diode in ON and OFF-state

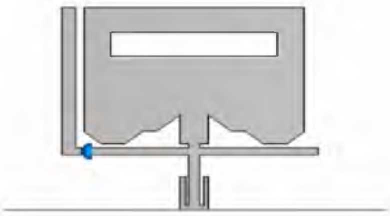


Fig. 5. Lumped element designed

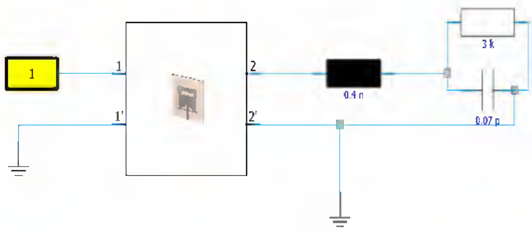


Fig. 6. Schematic design of PIN diode using CST Microwave studio

IV. Simulated Results

The proposed antenna structure was designed and simulated using CST Microwave Studio to analyze its return loss and radiation pattern. A PIN diode is integrated into the slot of the antenna.

PIN Diode in OFF and ON States:

In the ON state of the diode, the proposed antenna resonates at a dual-frequency band. Fig.7 shows the simulated return loss of the proposed antenna, which is observed to be below -10 dB, specifically at -37.5 dB and -26.88 dB at the resonating frequencies of 5.2 GHz and 2.7 GHz, respectively. Conversely, in the OFF state, where the PIN diode has a capacitance value of C = 0.07 pF, the proposed antenna resonates at two frequency of 2.4 GHz and 2.5GHz , with a return loss observed to be below -10 dB, specifically at -30 dB and -24.5 dB.

The simulation results demonstrated a notable agreement between the use of a PEC (Perfect Electric Conductor) pad and the PIN diode within the antenna design, suggesting the potential for their interchangeability without significantly impacting the overall antenna performance.

Furthermore, the simulation highlighted an additional advantage of using the PIN diode, as it maintained a good adaptation of frequency range, alongside the emergence of additional resonant frequencies, the most prominent of which was at 2.5 GHz.

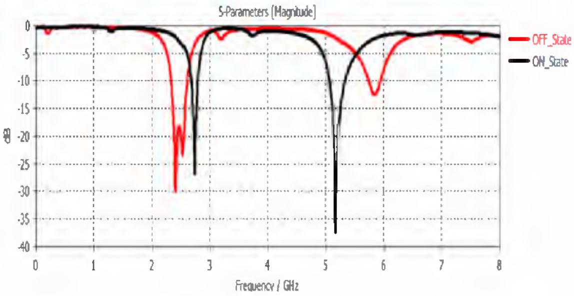


Fig. 7. Simulated return loss S_{11} of the proposed antenna

The surface current distribution Fig.8 clearly demonstrate a significant change in the path and intensity of currents on the antenna's surface depending on both the operating frequency and the antenna's different states (ON and OFF). Across the various frequencies (2.73 GHz, 5.2 GHz, 2.4 GHz, 2.5 GHz) and states, the current distribution on the metallic patch exhibits a unique pattern characterized by a primary concentration of current around the feedline with varying extensions and distributions across the patch's slots, which underscores the fundamental mechanism for achieving reconfigurability in this design.

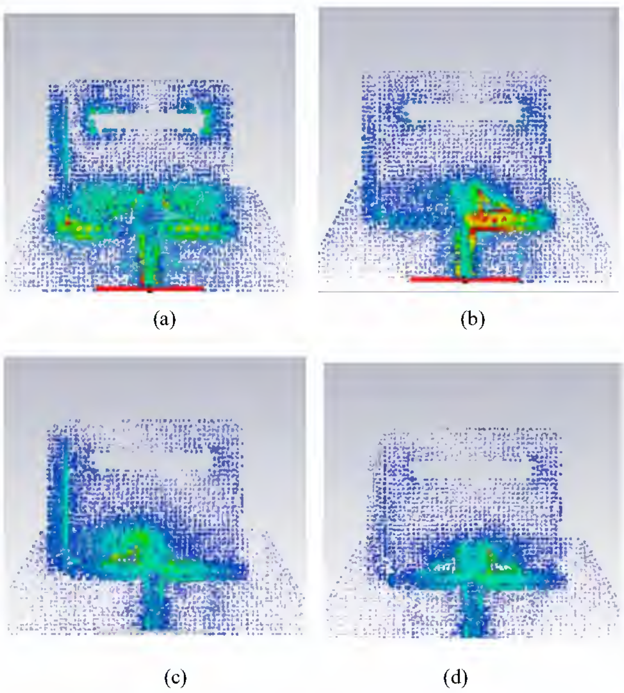
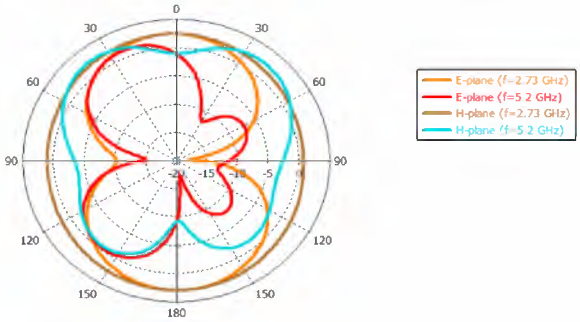


Fig. 8. Surface current distribution in differents states, ON state at (a) 2.73 GHz and (b) 5.2GHz, OFF states at (c) 2.4GHz and (d) 2.5GHz

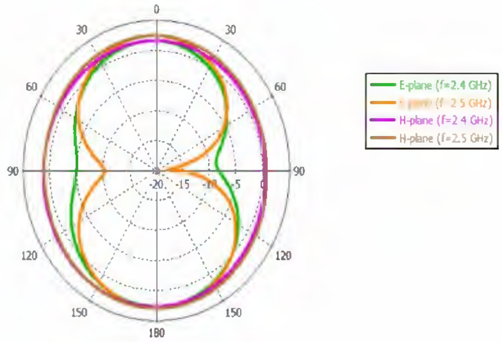
Frequency Reconfigurability: The fig.9 illustrates how the radiation pattern changes noticeably when the antenna's state is switched (ON to OFF), indicating the antenna's frequency reconfigurability capability.

* Directivity: The antenna appears to exhibit higher directivity generally at the higher frequencies in both states (5.2 GHz in the ON state and 2.5 GHz in the OFF state) within the E-plane.

* Coverage: In the H-plane, the antenna tends to provide broader coverage (quasi-omnidirectional) at the lower frequencies in both states.



(a)



(b)

Fig. 9. The radiation patterns of the Prorposed RA in the E-plane and H-plane at different states, (a) ON state, and (b) OFF state.

V. Conclusion

Leveraging a single PIN diode as a control switch, a compact frequency-reconfigurable antenna targeting 5G applications within the 2.4 and 5.2 GHz bands has been developed. Simulations conducted using CST Microwave Studio demonstrated good performance in terms of impedance matching and radiation patterns across both bands. Surface current distribution analysis revealed the mechanism through which altering the state of the single diode modifies the antenna's characteristics. This approach represents a simplified and effective design for a multi-band antenna that meets the requirements of modern 5G applications.

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