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A Double Band Notch Antenna with Flexible Frequency Tuning for Ultra Wideband Applications

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Abstract

Objectives: To develop a flexible double-band notched UWB antenna with frequency reconfigurable characteristics. **Method:** Meander slots on the radiating patch and ground structure are used to achieve dual band notches. PIN diodes are used to obtain frequency reconfiguration. **Findings:** Simulation analysis through HFSS shows a single band notch at 8.6 GHz when both diodes are ON and two notches are obtained at 5.3 GHz and 8.6 GHz when both diodes are OFF. The antenna's radiation pattern is omnidirectional. The findings reveal that the UWB antenna design offers valuable advantages, including the ability to notch specific frequency bands (dual band notching at 5.5 GHz and 8.6 GHz), ensuring compliance with regulatory standards, reducing interference, both in single and dual notch configurations, while maintaining an omni-directional radiation pattern (5 dBi). The design offers precise control over frequency rejection and hence flexible in design, enhancing versatility in wireless communication systems. **Novelty:** The performance characteristics, such as frequency tunability in the notch band, using the described method are a novel concept to the author's knowledge.

Keywords: Band Notch; PIN diodes; Reconfigurable antenna; Slot antenna; UWB

1 Introduction

Ultra-Wideband (UWB) band-notch antennas are a captivating field in antenna design, gaining recent attention. These antennas operate across a wide electromagnetic frequency spectrum, excelling in selectively attenuating specific frequency bands while performing well in others, making them vital for applications involving interference mitigation and coexistence with other wireless systems.

The Federal Communications Commission (FCC) introduced Ultra-Wideband (UWB) systems back in 2002, offering a wide bandwidth from 3.1 GHz to 10.6 GHz for indoor wireless communications[(1)]. This innovation garnered significant attention among researchers due to the appealing features of UWB systems, such as their affordability, high data rates, and robustness against interference[(2–4)]. However, a substantial challenge arises from the broad bandwidth of UWB, as it often overlaps with existing narrow-band communication applications like WLAN, C-band, X-band, and WiMAX. To mitigate potential interference in these situations, narrow-band stop filters (BSFs) are typically employed, though this adds to the overall cost. In response, various UWB antenna designs with notched frequency bands have been developed using techniques like slot etching[(5,6)], stub insertion[(7)], integrated filters[(8,9)], defected ground structures[(10,11)], multiple resonators[(12)] aiming to minimize interference while maintaining compatibility with narrow-band systems.

Despite these efforts, a critical research gap becomes evident as the demand for radio spectrum continues to grow. The current UWB antenna designs are limited in their ability to dynamically adapt to the evolving landscape of low-cost systems, diverse communication protocols, and high-data-rate wireless communications, especially below 10 GHz, where numerous systems operate, such as WLAN, C-band, RFID, and X-band. This calls for antennas that can adjust their operating modes dynamically to accommodate multimode wireless communication and cognitive radio applications. Researchers are exploring intelligent approaches, including cognitive radio and software-defined radio techniques, to develop UWB Cognitive Radio Antennas (CRAs) with more complex structures. However, the focus is also on addressing the limitations of single UWB CRAs, which have faced challenges like electromagnetic wave leakage and radiation pattern degradation due to the incorporation of split-ring resonators (SRR) in their designs.

This paper presents a comprehensive study on a flexible double-band-notched ultra-wideband (UWB) antenna that possesses frequency reconfigurable characteristics. The dual-band notches are achieved through the incorporation of meander slots on both the radiating patch and the ground structure. To enable reconfiguration of the notched bands, a PIN diode is utilized. The implementation and performance analysis of the antenna, considering its flexible design and the ability to dynamically adjust the notched bands, are thoroughly investigated in this research.

2 Methodology

Figure 1 showcases the proposed antenna design, which exhibits a circular radiating patch with a radius of 11mm. The substrate employed in this design is Rogers RO4350B, possessing a dielectric constant of 3.48. In order to transform the antenna into a monopole antenna, a partial ground is incorporated. Additionally, two meander slots are etched, one on the radiating patch and the other on the ground plane. The meander slot on the radiating patch serves the purpose of introducing a band notch within the 4 to 6 GHz frequency range. This particular notch in the frequency response aids in suppressing or attenuating signals within that specific range, potentially eliminating interference or unwanted signals in that band. On the other hand, the meander slot on the ground plane introduces a band notch within the 8 to 9 GHz frequency range. By incorporating this notch, signals falling within this frequency range can be effectively attenuated or suppressed, enabling better performance and reducing potential interference issues. To achieve a continuous meander slot structure, two pin diodes are inserted into the slots on the radiating patch. The inclusion of these pin diodes allows for dynamic control over the meander slot, enabling adjustments to the antenna's performance characteristics. By selectively controlling the diodes' biasing, the shape and properties of the meander slot can be altered, providing flexibility in tuning the antenna's performance. The dimensions of the antenna are shown in Table 1. The fabricated prototypes- front view and rear view are also shown in Figure 1. The section describes the equivalent circuit of a PIN diode under both on and off conditions, with specific values for the components involved. The circuit diagram is represented in Figure 2.

Table 1. Specifications of Antenna designed using HFSS

Parameters	Specification
Wsub	32mm
Lsub	35mm
L	1mm
Lgp	11mm
W	7mm
R	11mm
D1	Diode 1
D2	Diode 2

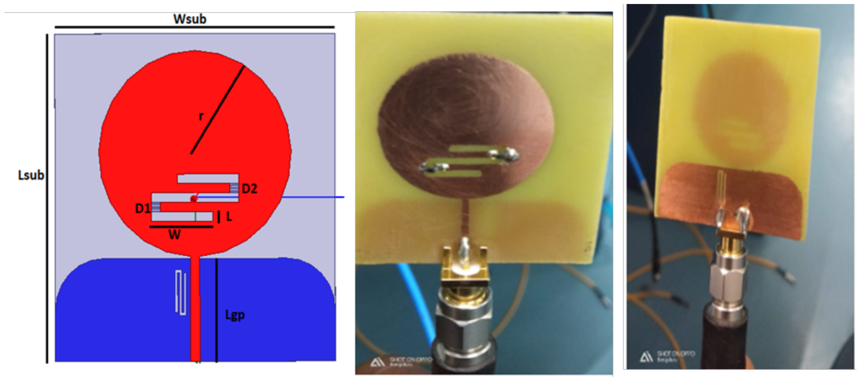

Fig 1. Proposed Antenna and its Fabricated Prototype

When the PIN diode is in the ON condition, the inductance and resistance are connected in series. The resistance has a value of 3.1 ohms, indicating the opposition to the flow of electric current. Additionally, the inductance has a value of 0.4nH, representing the property of storing energy in a magnetic field. Conversely, in the OFF condition, the inductance is connected in series to a parallel combination of a resistor and a capacitor. The resistance value increases to 3.12 kilo ohms, while the capacitance measures 0.17 pico farads. The resistor provides the same function as in the ON condition, opposing the current flow, while the capacitor allows for the storage and release of electrical energy.

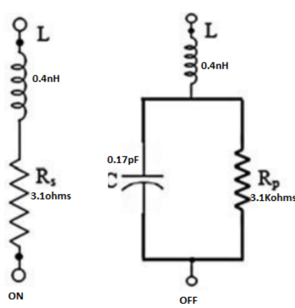

Fig 2. Equivalent circuit of PIN diode under ON and OFF condition

3 Results and Discussions

The experimental setup to measure the antenna performance is shown in Figure 3. The designed antenna is connected to vector network analyzer (ZNB40) with frequency range of 100 kHz to 40 GHz.

Figure 4 displays the simulated return loss plots of an antenna that does not have any slots on it. The plots reveal that the antenna operates across a broad frequency range, specifically from 3GHz to 12GHz. Both the simulation and measured plots are in good agreement with each other. The return loss plot provides valuable information about the antenna's performance by indicating how well it rejects or reflects signals at various frequencies. In this case, the wide bandwidth of operation suggests that the antenna is capable of efficiently transmitting and receiving signals across a significant frequency range, making it suitable for diverse applications requiring communication or reception within the specified frequency band. Figure 5 shows VSWR plot of circular antenna with meander slots when both diodes off. It is observed that VSWR < 2 in the operational bandwidth of 3-10 GHz.

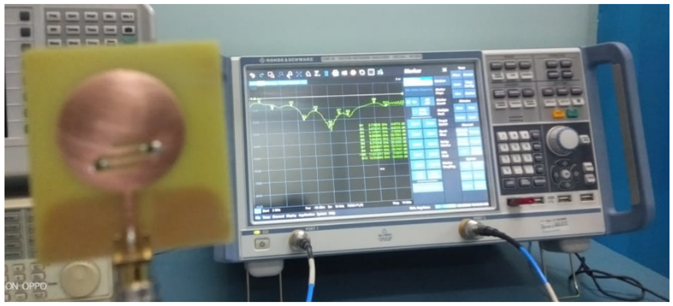

Fig 3. Experimental setup

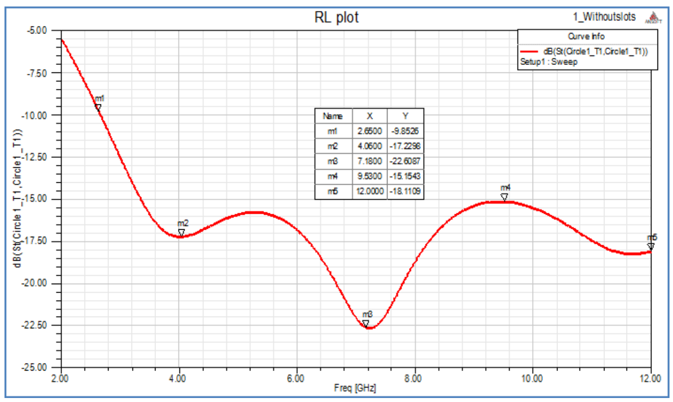

Fig 4. Simulated Return Loss plot of circular antenna without meander slots

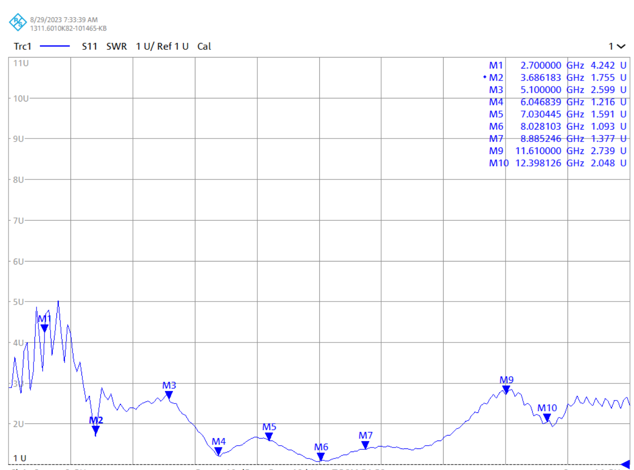

Fig 5. Measured VSWR plot of circular antenna with meander slots& both diodes OFF

Figure 6 describes the implementation of two meander slots, one on the patch and one on the ground plane of an antenna. These slots result in the observation of two band notches, which are dips or regions of reduced signal strength in the antenna's frequency response. The first band notch appears at a frequency of 5.1GHz and is attributed to the slot on the patch. The presence of this slot causes a specific frequency to be attenuated or suppressed. Similarly, the second band notch occurs at a frequency of 8.23GHz and is associated with the slot on the ground plane. This slot also leads to the suppression of signals at a specific frequency. In order to enable reconfiguration of the band notch frequency, a solution was implemented by introducing two diodes onto the slot located on the patch of the antenna. The impact of these diodes on the band notch frequency is demonstrated in Figures 7, 8 and 9. Figures 7 and 8 depicts the scenario of return loss plots for simulation and measured results when both diodes are in the OFF state, while Figure 9 represents the situation when both diodes are in the ON state. Examining the graph, we observe that when both diodes are OFF, a dual band notch at 5.5GHz and 8.6 GHz is achieved. This means that the signal strength is significantly reduced or suppressed at this specific frequency.

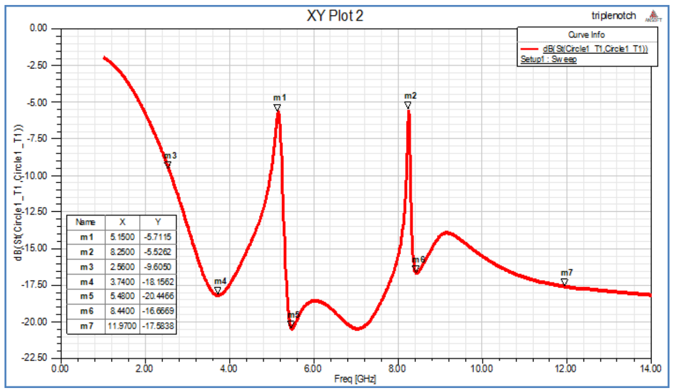

Fig 6. Return Loss plot of the antenna with two meander slots

On the other hand, when both diodes are turned ON, the configuration results in the presence of single band notch. This notch occurs at frequency 8.51 GHz. Consequently, by switching the diodes between the ON and OFF states, it becomes possible to achieve reconfiguration of the band notches. This reconfiguration capability is valuable as it allows for the customization and adaptation of the antenna's frequency response according to specific requirements. By controlling the state of the diodes, different band notches can be obtained, opening up possibilities for various applications that necessitate precise frequency manipulation and rejection.

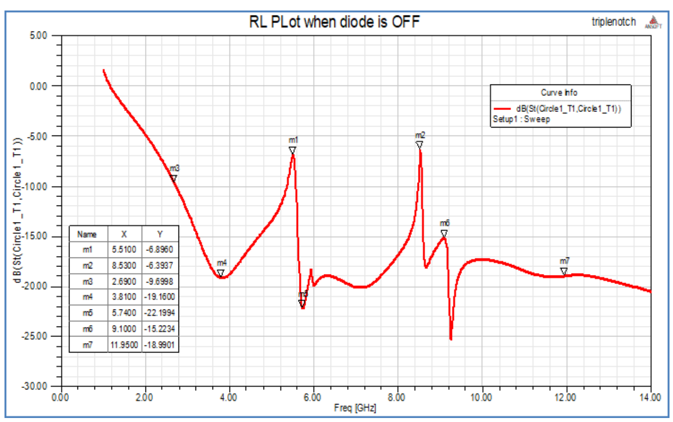

Fig 7. Simulated Return Loss plot with both diodes OFF

Figures 10 and 11 depicts the proposed antenna's radiation pattern with the diode both ON and OFF. Figure 10 illustrates how the antenna radiation pattern is omni-directional in both scenarios. Additionally, it has been shown that PIN diode antenna frequency changing has no influence on the antenna's radiation pattern. The comparison result between simulation and tested results are presented in Table 2 for DIODE OFF condition. As seen in Table 2 both the simulation and measured results are in

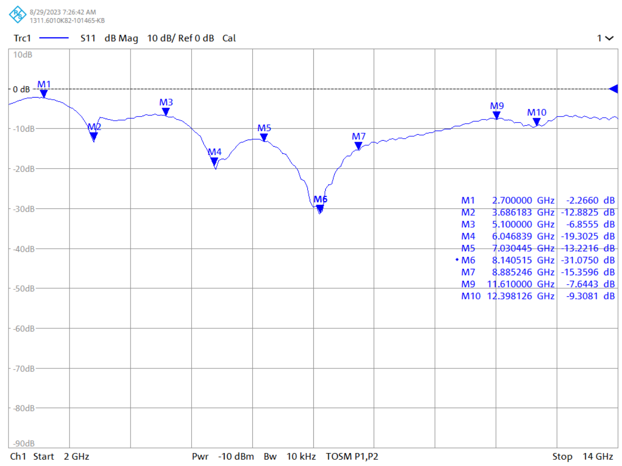

Fig 8. Measured Return Loss plot of circular antenna with meander slots when DIODE is OFF

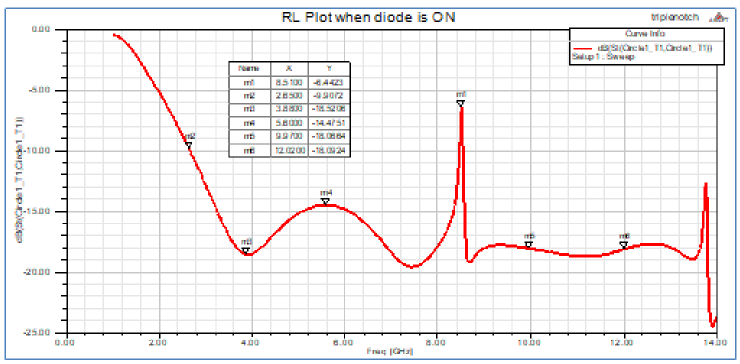

Fig 9. Return Loss plot with both diodes ON

good agreement with each other that validates the results.

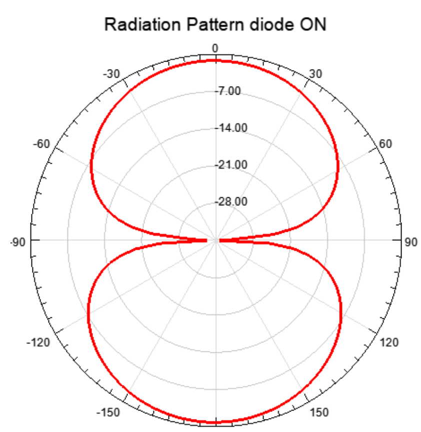

Fig 10. Diode ON

Comparison of the proposed antenna results with the existing literature is shown in Table 3. While[13] covers the 2.4-5.37 GHz and 5.15-5.725 GHz bands, it lacks the tunability and advanced band-notch capabilities of the proposed antenna. The proposed antenna's wider frequency range and dynamic control options make it more adaptable to a broader range of

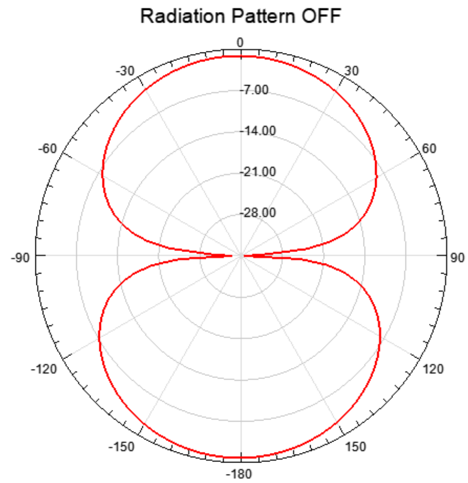

Fig 11. Diode OFF

Table 2. Comparison between Simulated and measured Results when DIODE is OFF

Parameter	Simulated	Measured
Band notch frequency	5.51 and 8.5 GHz	5.1 and 9 GHz

applications. Although [14] offers tunability, the reference paper does not provide the same level of band-notch capabilities and omni-directional radiation patterns as the proposed antenna. The proposed antenna's additional advantages in these areas make it more robust in terms of interference mitigation and signal coverage. [15] operates at specific frequencies (5.6 GHz & 9.6 GHz) without the flexibility and advanced band-notch capabilities of the proposed antenna. The tunable and band-notching features of the proposed antenna give it a broader scope of functionality. Unlike most existing antennas that operate at fixed frequency bands, the proposed antenna offers dynamic tunability. It can switch between different frequency bands, specifically from 5.5 GHz to 8.6 GHz, allowing it to adapt to varying interference levels and coexist harmoniously with other wireless systems. This dynamic control is a significant novelty that enhances its versatility and interference mitigation capabilities. The proposed antenna features an advanced band-notch capability, with the ability to notch out specific frequencies (ON - 8.6 GHz, OFF - 5.5 and 8.6 GHz). This level of precision in interference mitigation is a novel and highly valuable feature, especially in environments with multiple frequency bands in use. Maintaining an omnidirectional radiation pattern while offering dynamic tunability and advanced band notch capabilities is a unique feature in this design. This ensures that the proposed antenna can provide consistent signal coverage in all directions, which is a novel trait compared to antennas that may have directional radiation patterns.

Table 3. Comparison of the proposed antenna with existing literature

References	Substrate	Feeding	Band notches	Frequency band	Radiation pattern	Tuneable
[13]	Kapton Polyimide	CPW	2.4-5.37 GHz – WLAN and WiMAX & 5.15-5.725 – Hyperlan/2	2.05 to 14 GHz	Omni directional 12.7db at 8.4GHz	No
[14]	F4B dielectric	Microstrip feeding	2.47-4.19 4.32–5.96 GHz WiMAX and WLAN band	1.3 – 11.6 GHz	Onmi directional radiation pattern	Yes
[15]	FR4 epoxy	Microstrip line feeding	5.6 GHz & 9.6 GHz	3.4 – 12.3 GHz	9.8dBi at	No
Proposed design	Roger substrate	Microstrip feeding	ON- 8.6GHz OFF – 5.5 and 8.6GHz	3-12GHz	Omni directional	Yes

4 Conclusion

This study has presented a comprehensive study on a flexible double-band-notched ultra-wideband (UWB) antenna with frequency reconfigurable characteristics. The incorporation of meander slots on both the radiating patch and the ground structure enabled the achievement of dual-band notches.

The introduction of PIN diodes facilitated the reconfiguration of these notched bands. Through simulation analysis, it was observed that when both diodes were in the ON state, a single band notch at 8.6 GHz was achieved. This configuration demonstrated the ability to attenuate or suppress signals at this specific frequency. On the other hand, when both diodes were turned OFF, the antenna exhibited two band notches at frequencies 5.5 GHz and 8.6 GHz. Both the simulation and measured results are in good agreement with each other. The proposed design novelty lies in its dynamic tunability, advanced band-notching capabilities, omni-directional radiation pattern, and the choice of Roger substrate material.

These features collectively make it a unique and promising contribution to the field of antenna design, offering a higher degree of adaptability and interference mitigation than many existing designs. Future work in band-notch antenna research should focus on innovative materials and miniaturization techniques to enhance antenna performance and adaptability in various wireless applications.

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