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Design of Frequency Reconfigurable Antenna with Split Ring Resonator and Diode Control for Omnidirectional Applications

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Abstract: - This paper presents a novel antenna design featuring frequency reconfiguration through the use of a diode. The antenna incorporates curved slots on the patch and a central circular-shaped split ring resonator, achieving dual-band operation. When the diode is ON, the antenna operates at 5.5 GHz and 7.1 GHz, and when the diode is OFF, it operates at 6.7 GHz and 7.6 GHz. The VSWR remains below 2 in both states, indicating efficient impedance matching. Additionally, the antenna maintains an omnidirectional radiation pattern regardless of the diode state, ensuring uniform signal distribution. The design employs a low-cost FR4 epoxy substrate and microstrip line feeding, balancing affordability and performance. This reconfigurable antenna is suitable for applications requiring flexible frequency tuning and reliable signal coverage.

Keywords: – Reconfigurable Antenna, Frequency Tuning, Split Ring Resonator, Microstrip Line Feeding, Omnidirectional Radiation Pattern.

I. INTRODUCTION

Patch antennas (PAs) are a type of directional antenna featuring a thin metal patch situated above a ground plane. These antennas are connected to a transmission line through a feed point. The operational frequency of a patch antenna is determined by its dimensions and shape.

In recent years, patch antennas (PAs) have gained popularity due to their compact size, low profile, and easy integration with other electronic components, making them favorable over traditional antennas [1,2]. Their small size, high gain, and durability are particularly appreciated in mobile device manufacturing and wireless communication systems, where they see widespread use. Research continues to focus on designing smaller and more efficient PAs to support high-speed data transmission, aiming to incorporate them into micro-electromechanical systems (MEMS) for integration into compact devices [3-8]. Advances in material technology and manufacturing techniques have recently enabled the creation of even smaller and higher-performing patch antennas [9-13]. The ongoing challenge of further miniaturizing PAs is an active area of research, with new techniques being developed to achieve this goal [14-17].

In wireless communication systems, two prevalent types of antennas are ultra-wideband (UWB) and multi-band antennas [18-21]. Both are capable of operating across a wide frequency range but have distinct characteristics and uses. Multi-band antennas are composed of several resonating elements, each calibrated to a specific frequency band, enabling them to function across multiple narrow bands. These antennas are ideal for applications that require communication across various frequencies, such as cellular networks and Wi-Fi systems [22-25]. Conversely, UWB antennas utilize a single resonant element to cover a broad spectrum, operating over a wide frequency range without needing multiple resonators.

Reconfigurable planar antennas have gained popularity for their versatility in switching between different modes of operation, frequencies, and radiation patterns, effectively combining the features of both multi-band and UWB antennas. These antennas are widely utilized in modern wireless communication systems, such as ultra-wideband (UWB) and wireless local area network (WLAN) applications [26-28], that require a broad range of frequencies. Recent literature has documented several approaches to achieving UWB characteristics, including tree-like fractal slots [29], compact folded network antennas, reconfigurable antennas with diodes on an FR4

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substrate [30-33], fractal arrays, and MIMO (multiple-input multiple-output) antennas. The incorporation of reconfigurable components,

like PIN diodes, enables these antennas to switch between different frequency bands, adapting to various communication needs. Designing such antennas is complex, necessitating electromagnetic simulations and optimization techniques to meet performance requirements.

II. PROPOSED DESIGN

The antenna depicted in Fig. 1 and Fig. 2 features curved slots on its patch, with a circular-shaped split ring resonator positioned at the centre to introduce an additional frequency band. The dimensions of the curved slot are meticulously designed to achieve the desired resonance within a compact form factor. Similarly, the size of the split ring resonator is precisely adjusted to attain a second resonance. This antenna employs microstrip line feeding and is constructed using an economical FR4 epoxy substrate, ensuring cost-effectiveness while maintaining performance. Using microstrip line feeding simplifies the antenna structure and enhances its integration with other components. The choice of an FR4 epoxy substrate is driven by cost-effectiveness and performance considerations. PIN diode is used to obtain frequency reconfiguration. The dimensions of the patch antenna are shown in Table. 1

Table 1: Antenna Specifications

Parameters	Specifications
Lg	10mm
Wg	10mm
g	0.5mm
l	5mm

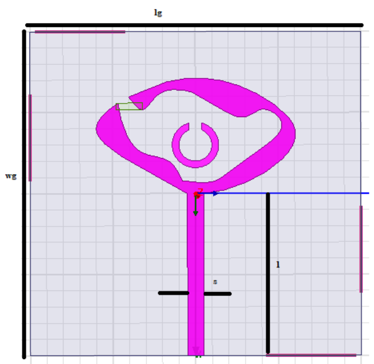

Fig. 1. Proposed Antenna Design

Fig. 2. Fabricated Prototype

III. PARAMETRIC ANALYSIS

Various configurations of the curved slot were explored to analyze their resonance behavior, as depicted in Fig 3. Through experimentation, we identified the optimal shape of the curve that facilitates achieving the desired design resonances.

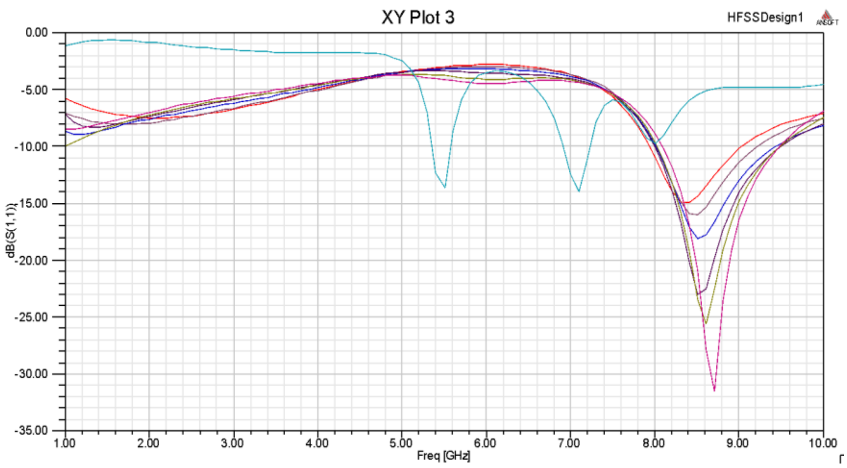

Fig. 3. Parametric Study of the proposed Antenna

IV. Results and Analysis

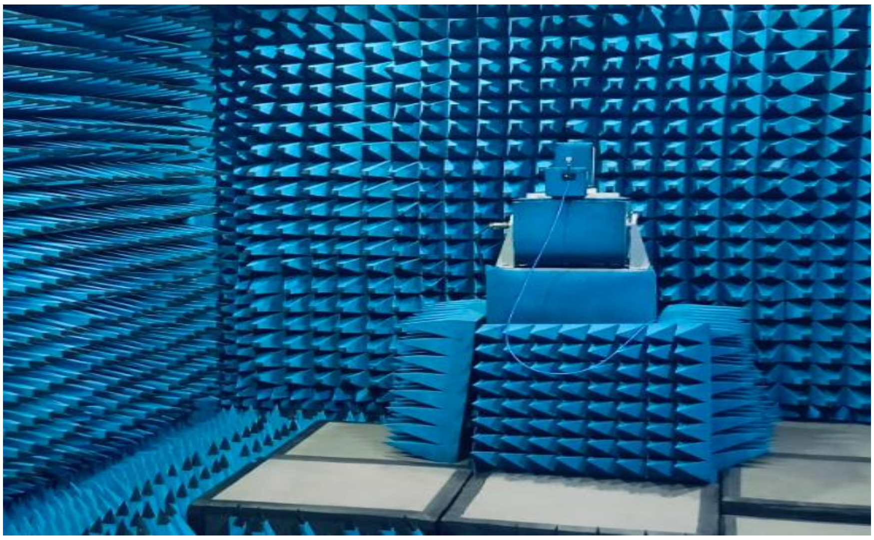

Fig. 4. Experimental Setup

The experimental setup is shown in Fig. 4. The antenna simulations are carried using ANSYS HFSS and tested using Vector Network Analyzer. Figures 5 illustrate the return loss of the proposed antenna design with the diode in the ON state. When the diode is ON, the antenna operates at two distinct frequency bands: 5.5 GHz and 7.1 GHz. Fig. 6 illustrate the return loss plot of the antenna when the DIODE is OFF. Conversely, when the diode is OFF, the antenna operates at different frequencies, specifically 6.7 GHz and 7.6 GHz. The measured return loss of the antenna in both the DIODE conditions correlate with the simulation results.

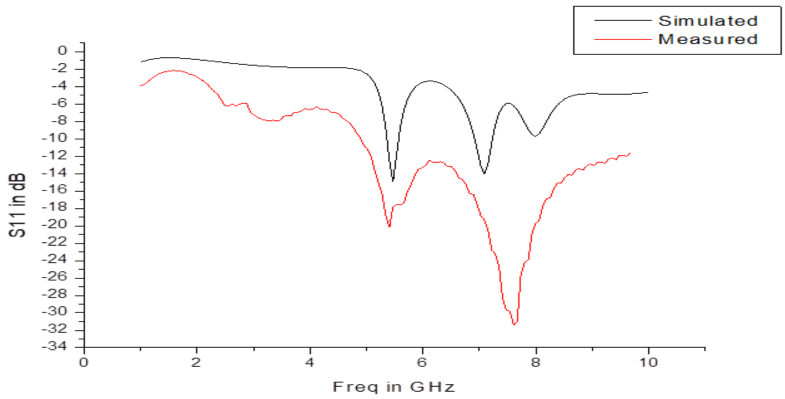

Fig. 5. Simulated and Measured Return Loss of the Antenna when DIODE is ON

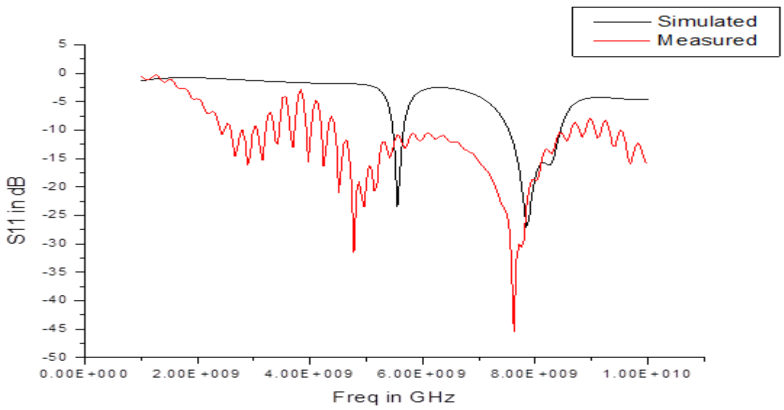

Fig. 6. Simulated and Measured Return Loss of the Antenna when DIODE is OFF

Fig. 7. Measured Return Loss of the Proposed Antenna when Diode is OFF

Figures 8 and 9 present the Voltage Standing Wave Ratio (VSWR) pattern of the proposed antenna with the diode in the ON and OFF states, respectively. The plots indicate that in both scenarios, the VSWR remains below 2, signifying efficient impedance matching and minimal signal reflection. Fig. 10 depicts the measured VSWR plot when the diode is OFF.

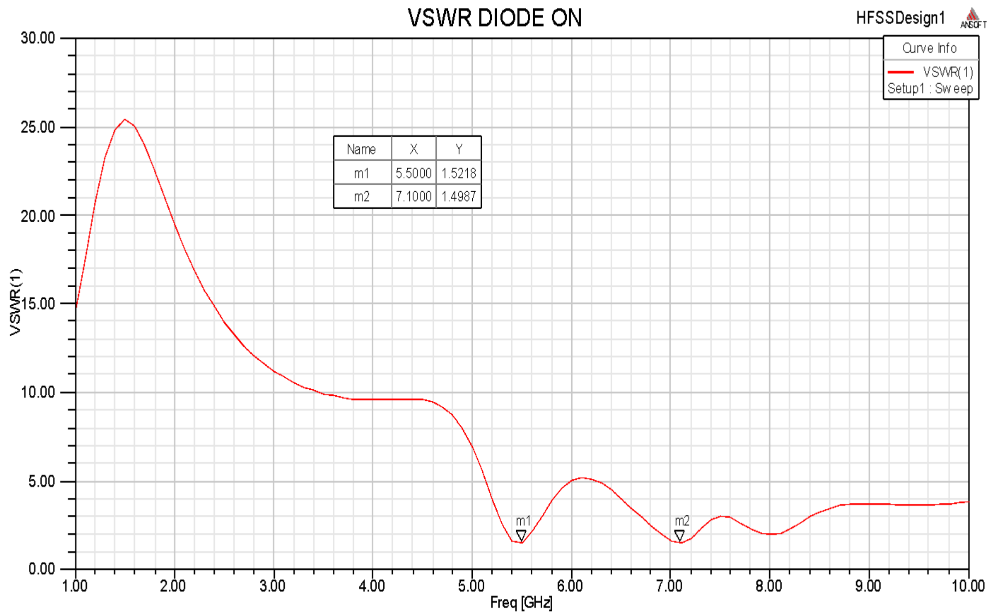

Fig. 8. VSWR plot of Antenna when diode is ON

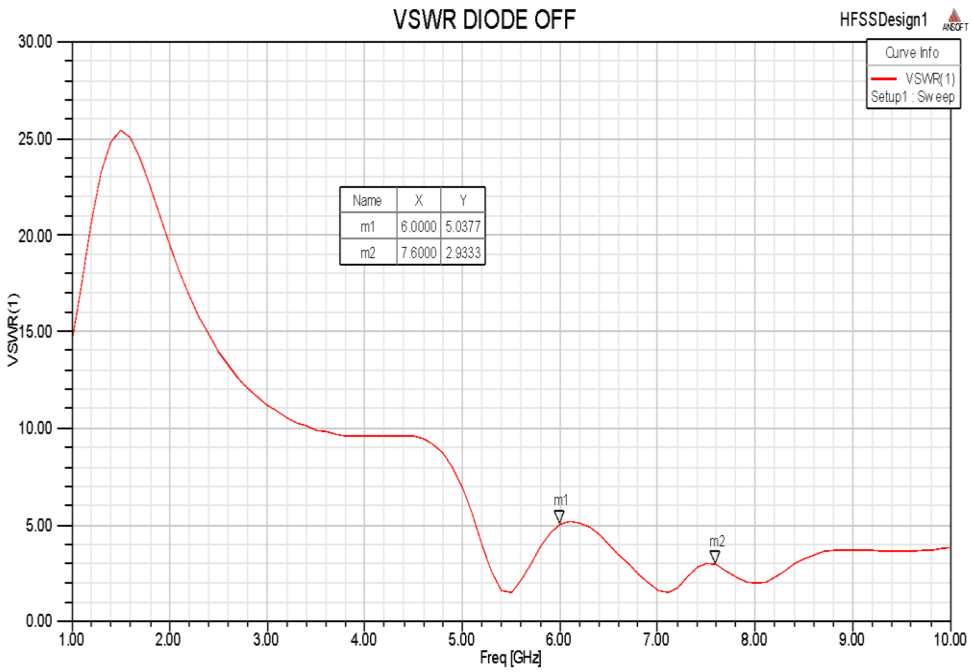

Fig. 9. Simulated VSWR plot of antenna when diode is OFF

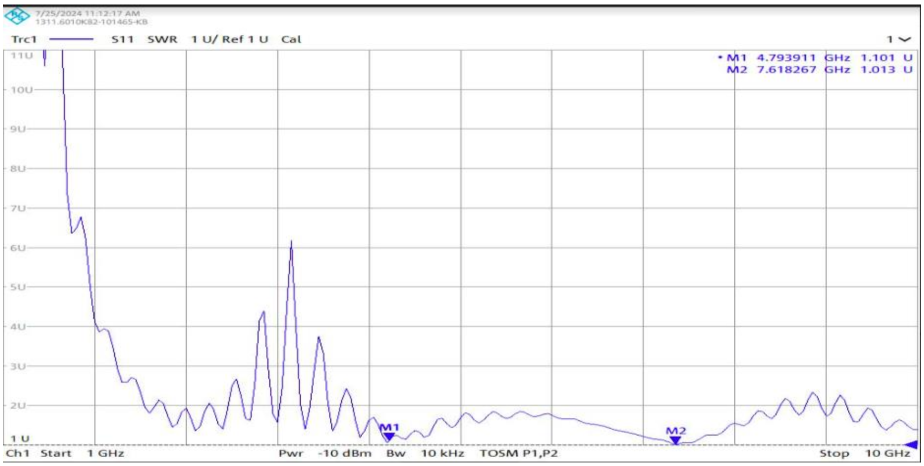

Fig. 10. Measured VSWR plot of antenna when diode is OFF

Figures 11 and 12 display the radiation patterns of the antenna for both diode states. Regardless of whether the diode is ON or OFF, the radiation pattern remains omnidirectional, ensuring uniform signal distribution in all directions. Fig. 13 shows the measured radiation pattern of the antenna at 7GHz.

DIODE ON

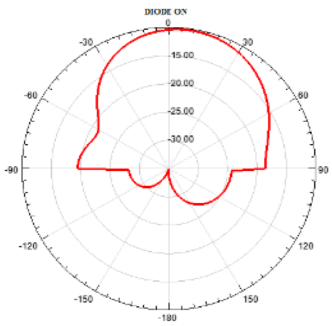

Fig. 11. Radiation pattern of the proposed antenna when diode is ON

DIODE OFF

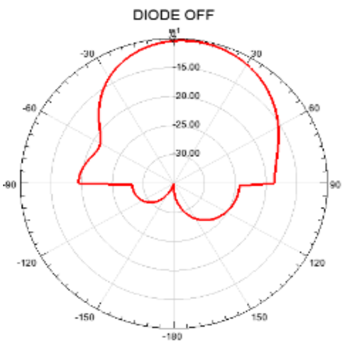

Fig. 12. Radiation pattern of the proposed antenna when diode is ON

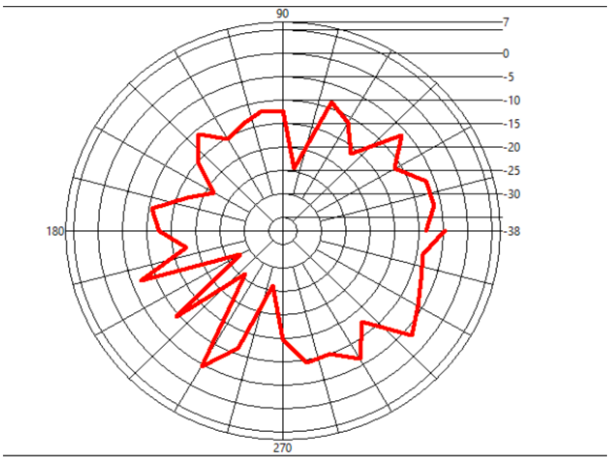

Fig. 13. Measured Radiation Pattern of the antenna at 7GHz

Table 2: Summary of the Results

Parameters	DIODE ON		DIODE OFF	
	Simulated	Measured	Simulated	Measured
	Freq in GHz	RL in dB	Freq in GHz	RL in dB
Operating Frequency	5.5	-13	6.04	-19
	7.1	-18	8.1	-31

Parameters	DIODE ON		DIODE OFF	
VSWR			Freq in GHz	VSWR
			5.5	1.52
			7.1	1.4
Radiation Pattern	Omnidirection al		Omnidirectio nal	

V. Conclusion

The proposed antenna design demonstrates effective frequency reconfiguration through the toggling of a diode, as evidenced by the distinct operational bands of 5.5 GHz and 7.1 GHz when the diode is ON, and 6.7 GHz and 7.6 GHz when the diode is OFF. The antenna maintains a VSWR below 2 in both diode states, indicating optimal impedance matching and minimal signal loss. Additionally, the antenna's omnidirectional radiation pattern, consistent in both states, ensures comprehensive signal coverage. Constructed with a low-cost FR4 epoxy substrate and featuring microstrip line feeding, this antenna design combines cost-effectiveness with high performance, making it a viable solution for applications requiring dynamic frequency tuning and robust signal propagation.

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