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Reconfigurable Dual Band Antenna using Varactor Diode

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ABSTRACT (12 PT)

This paper presents a dual-band frequency reconfigurable microstrip antenna integrated with an Electromagnetic Band Gap (EBG) structure for modern wireless communication applications. The proposed antenna operates at two key frequency bands of 1.8 GHz and 2.4 GHz and is fabricated on a Rogers 4003C substrate to achieve low dielectric loss and stable radiation performance. Frequency reconfigurability is achieved by embedding varactor diodes across strategically etched slots on the radiating patch, allowing continuous tuning through DC bias voltage control without altering the physical structure of the antenna. The EBG structure is employed to suppress surface wave propagation and enhance antenna gain and radiation stability. Simulation and experimental results demonstrate effective frequency tuning from 1.68–1.88 GHz and 2.38–2.81 GHz with stable impedance matching and directional radiation patterns. The proposed antenna is suitable for compact and reconfigurable wireless systems such as IoT and 5G applications.

1. INTRODUCTION

With the rapid advancement of wireless communication technologies, the demand for antennas that offer compactness, high performance, and frequency agility has grown significantly. Among various antenna types, dual-band reconfigurable antennas have garnered attention for their ability to adapt to different frequency bands, improving system flexibility and spectral efficiency[1], [2].

These antennas are particularly valuable in modern communication systems such as Internet of Things (IoT), 5G, wearable devices, and mobile platforms, where limited space and multi-band operation are critical constraints[2], [3].

A persistent challenge in multi-antenna systems is mutual coupling between antenna elements, which can lead to degraded performance such as pattern distortion, reduced gain, and increased signal correlation. One effective strategy to address this issue is the integration of Electromagnetic Band Gap (EBG) structures[3], [4]. EBGs are periodic materials engineered to suppress surface waves within specific frequency bands, acting as high-impedance surfaces that enhance antenna isolation, improve gain, and control radiation patterns[3], [4]. In this work, the EBG is adopted for the gain improvement, and the mutual coupling reduction is not focused as the proposed antenna is not a MIMO antenna.

In this study, a dual-band tunable microstrip antenna is designed and implemented using a Rogers 4003C substrate and enhanced with a square-shaped EBG array[5], [6]. The antenna is intended to operate at two key frequency bands—1.8 GHz and 2.4 GHz—suitable for various wireless applications [2] To introduce frequency reconfigurability, varactor diodes are strategically embedded within the antenna slots. These allow continuous frequency tuning through DC bias voltage without altering the antenna's physical geometry[7], [8].

The proposed antenna design is modeled and simulated using CST Studio Suite, and its performance is verified through comprehensive simulation analysis. The results demonstrate consistent frequency tuning, gain enhancement, and pattern stability across both bands, validating the design's robustness and practical applicability. This work contributes to the development of compact, efficient, and tunable antennas that are well-suited for integration in modern multi-band communication systems[9], [10].

2. METHODS

The proposed design focuses on developing a dual-band tunable microstrip antenna. It is integrated with a square-shaped Electromagnetic Band Gap (EBG) array and it aims to enhance performance in parameters such as gain, frequency reconfigurability, and radiation stability. The antenna target operation at 1.8GHz and 2.4GHz, two widely used bands in wireless communication systems.

2.1. Antenna Design Substrate Selection

The antenna is constructed on a Rogers 4003C substrate. The substrate is selected due to for its low dielectric loss and stable performance at microwave frequencies. Key dimensions of the antenna layout such as patch width, slot length, and ground plane size were optimized to ensure dual-band resonance.

Figure 1 depicts the antenna structure and the integration with EBG layer. As for the antenna, two distinct rectangular patches were used in the array to resonate at the desired frequency bands. The layout includes ground-plane modifications and slot etching to support the incorporation of tuning elements and improve frequency isolation between the bands. The dual-band antenna configuration is shown in Figure 1a and b. Figure 1a shows the top view of the antenna. The configuration of the antenna with EBG is presented in [16]. In this work, the dual-band antenna is further modified to perform independent reconfiguration

2.2 EBG Structure Design

A square EBG unit cell was designed to function as an artificial magnetic conductor (AMC), enhancing radiation efficiency by suppressing surface waves and back radiation. Two different EBG lattice constants were used (Figure 2)

- a = 20 mm for the 1.8 GHz band

- a = 16 mm for the 2.4 GHz band

Each EBG was modelled and simulated independently to verify its reflection phase characteristics. The structures showed a reflection phase near 180°, confirming their role as effective directors and reflectors depending on placement

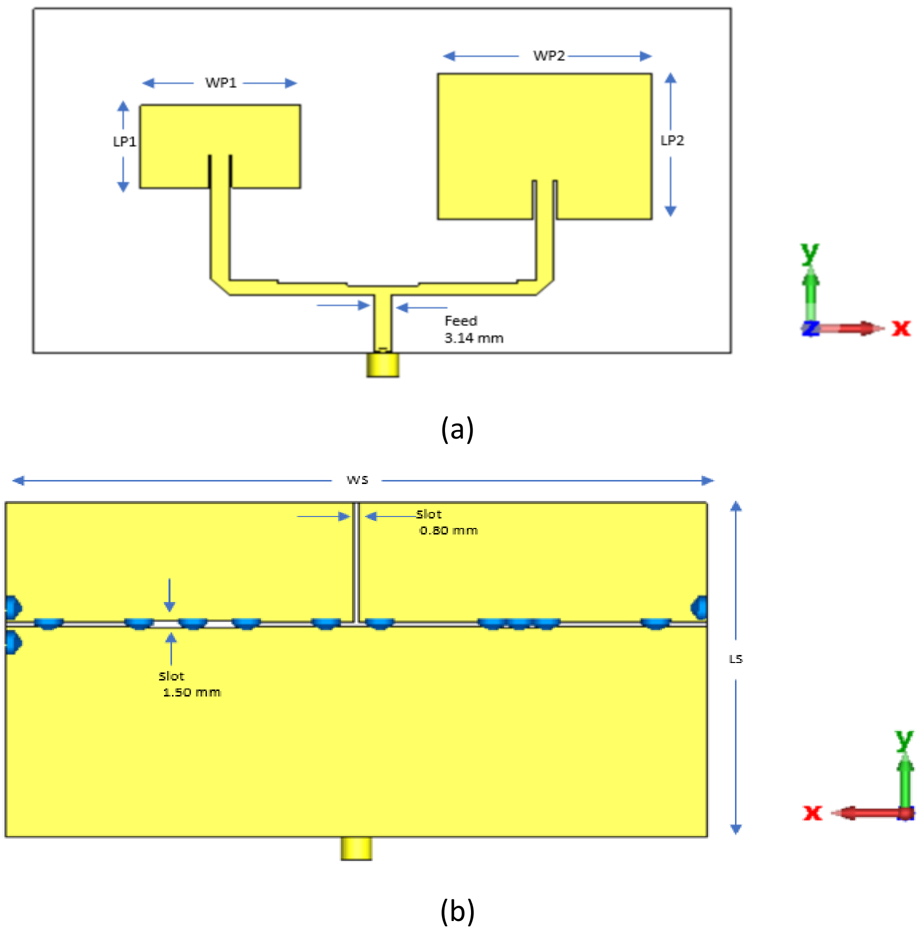

Figure 1. Tunable dual-band antenna with EBG array (a) Top view, (b) Bottom view

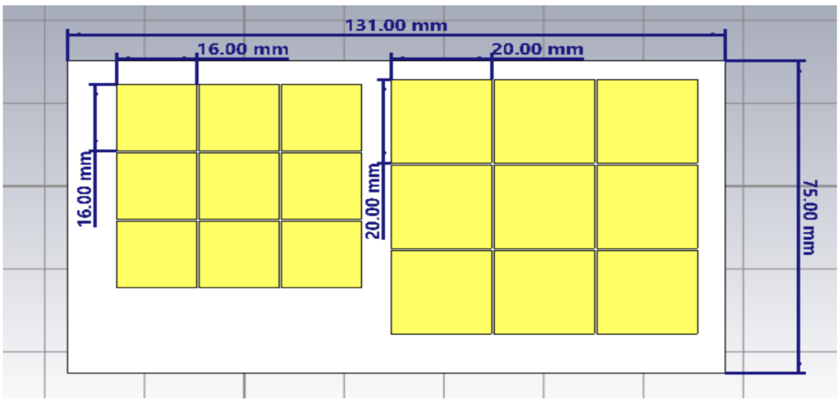

Figure 2. EBG unit cell design[16]

Table 1. Optimized design parameters of the dual-band antenna.

Parameter	Value
W_s	131 mm

L_s	75 mm		
Frequency	**3.3 GHz**	***Frequency***	**2.4 GHz**
Parameter	**Value**	***Parameter***	**Value**
Wp1	30 mm	*Wp2*	40 mm
Lp1	18 mm	*Lp2*	32 mm

2.3 Frequency Reconfiguration using varactor diode

To achieve dynamic frequency control, varactor diodes (SMV1232) were placed across slots etched on the antenna's radiating surface. These diodes allow smooth capacitance variation in response to DC bias voltage, enabling real-time frequency reconfiguration.

A DC biasing network was developed using high-impedance RF chokes and DC-blocking capacitors to isolate the control signals from RF paths. Slots and vias were carefully positioned to minimize disruption to current flow while preserving independent control of each diode.

Table below shows the tuning behaviour based on certain reverse bias voltage:

The tuning range achieved in simulation was:

- 1.68 GHz to 1.88 GHz (Lower band)
- 2.38 GHz to 2.81 GHz (Upper band)

V_R (V)	Capacitance (pF)	Tuned Frequency
0	4.15	f1
5	1.05	f6
10	0.76	f11
13	0.73	f14

Table 2. Reverse bias voltage versus varactor capacitance

2.4 Simulation and Measurement setup

All simulations were carried out using CST Studio Suite, focusing on the following parameters:

- S-parameters (S11 and S21) for impedance matching and isolation
- Dispersion diagram for EBG characterization
- 3D far-field radiation patterns for beam analysis

Gain and efficiency measurements across tuning ranges .

The optimized design was fabricated using standard PCB etching techniques. Experimental validation involved:

- Vector Network Analyzer (VNA) for S-parameter measurement Anechoic chamber for gain and pattern analysis Careful calibration to account for material loss and connector mismatch

3. RESULTS AND DISCUSSION

The performance of the proposed dual-band tunable antenna integrated with Electromagnetic Band Gap (EBG) structures and varactor diodes was evaluated through both simulation and experimental measurements. Key performance metrics include S-parameters, radiation patterns, gain, and frequency tunability.

3.1 Reflection Coefficient (S11) Analysis

The S11 parameter was used to evaluate impedance matching and frequency reconfigurability. The antenna was tested under varying DC bias voltages across the varactor diodes. As the reverse bias voltage increased, the capacitance decreased, resulting in a shift in resonant frequency.

- Lower band tunable from 1.68 GHz to 1.88 GHz
- Upper band tunable from 2.38 GHz to 2.81 GHz

These shifts confirm effective control of resonant frequencies using the varactor-loaded slots. The antenna maintains return loss better than –10 dB across both bands, indicating strong impedance matching.

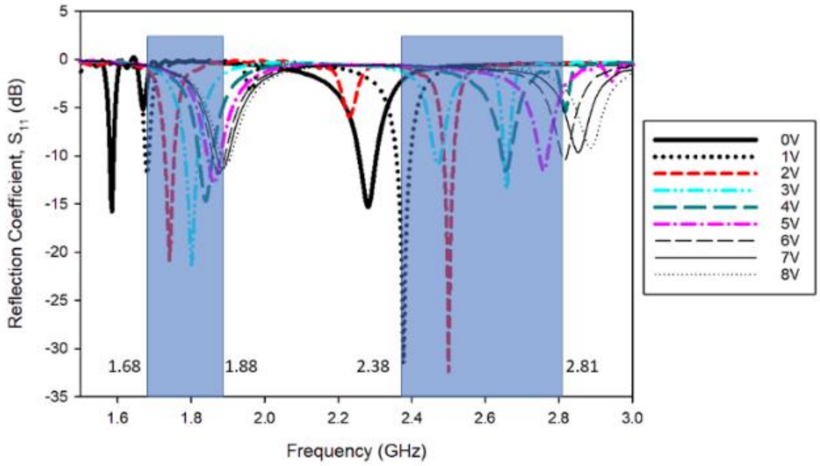

Figure 1: Frequency reconfiguration of the lower band

3.2 EBG Performance analysis

The EBG structures used in this design served dual purposes—enhancing gain and reducing mutual coupling. The reflection phase of the unit cells was simulated using CST Microwave Studio.

- The 20 mm EBG designed for the 1.8 GHz band exhibited a reflection phase near 180°, indicating a director behavior.
- The 16 mm EBG for the 2.4 GHz band acted as an AMC within the phase range of +90° to –90°, effectively serving as a reflector.
- These results validate the EBG's effectiveness in manipulating the radiation pattern and suppressing surface waves, contributing to overall gain improvement.

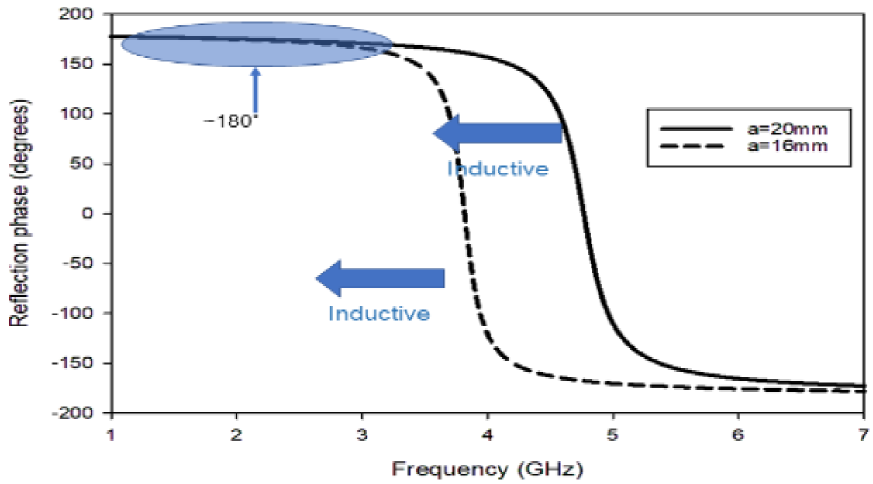

Figure 4: EBG metasurface results

3.3 Radiation pattern and Gain

Radiation patterns were simulated in 3D for various tuning states to ensure pattern stability and performance across the tuning range.

- At 1.68 GHz and 1.74 GHz (lower band), the patterns were consistent with an average gain of 5.5 dBi.At 2.38 GHz and 2.5 GHz (upper band), the patterns were also stable, showing a gain of approximately 6 dBi.

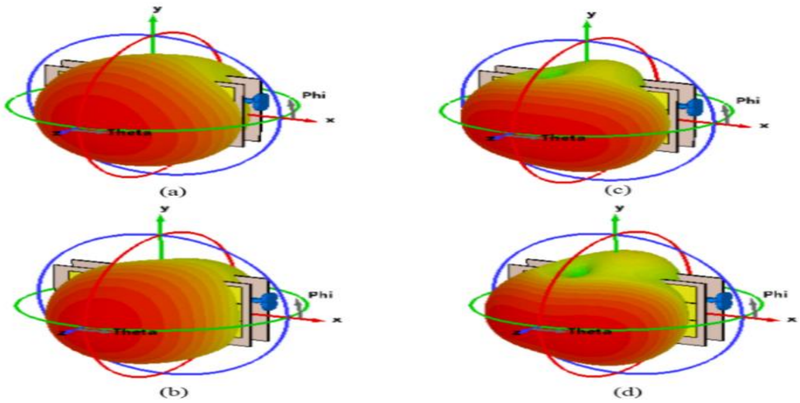

Figure 2: The 3D simulation results (a) 1.68 GHz, (b) 1.74 GHz, (c) 2.38 GHz and (d) 2.5 GHz

3.4 Measured Results and Discussion

The integration of varactor diodes provided smooth tuning without requiring mechanical alterations,[12], [15] while the EBG structures improved gain and isolation.[3], [13] The combination of these two techniques resulted in an antenna that meets the requirements of modern wireless systems—compactness, reconfigurability, and radiation performance stability.[1], [2], [9]

Compared to previous works:

- This design offers a broader tuning range.[5], [7]
- It demonstrates better gain enhancement through EBG loading. [6], [13], [14]
- It uses a simple biasing network without affecting pattern stability.[11], [15]

4. CONCLUSION

This research successfully demonstrated the design, simulation, and experimental validation of a dual-band frequency reconfigurable microstrip antenna integrated with Electromagnetic Band Gap (EBG) structures and varactor diodes. The antenna is optimized to operate at 1.8 GHz and 2.4 GHz, which makes it suitable for modern wireless communication applications. The implementation of square-shaped EBG arrays enhances the antenna's performance by putting down surface waves and reducing mutual coupling, which contributes to gain improvement and radiation pattern stability. At the same time, the incorporation of varactor diodes has enabled effective and smooth frequency reconfiguration within each band by applying a DC bias, and achieved a tunable range of 1.68–1.88 GHz and 2.38–2.81 GHz. Simulation results showed strong correlation, validating the antenna's impedance matching, directional radiation, and stable gain performance. This study shows that combining EBG structures with tunable elements can give compact and efficient antennas with enhanced functionality. The proposed design provides a solution for future applications in wearable technology, IoT, and 5G networks, where multi-band operation and reconfigurability are critical

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