Design and Analysis of Microstrip Patch Antenna Utilizing Mushroom Like-EBG for Wireless Communications

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Abstract - In this paper, a compact mushroom-like Electromagnetic Band Gap (EBG) integrated microstrip patch antenna is designed to operate at 2.4 GHz for wireless communication applications. CST Studio Suite is used to design the antenna, which is then optimised to obtain improved performance in terms of bandwidth, impedance matching, and return loss. The proposed design has a substrate thickness of 1.6 mm and compact dimensions of 76 mm × 58 mm. The antenna uses a 50 Ω microstrip line-fed arrangement and is fabricated on a FR-4 substrate. Surface wave suppression and radiation properties were greatly enhanced by the incorporation and optimisation of the mushroom-like EBG structures surrounding the radiating patch. The optimised design's suitability for 2.4 GHz wireless communication systems is confirmed by its return loss of -21.88 dB and VSWR of 1.079 at 2.414 GHz with a bandwidth of 110 MHz.

***Key Words*:** *Micro strip Patch Antenna, Mushroom-like EBG, Wireless Communications, Antenna Design, Bandwidth Enhancement, Surface Wave Suppression, Radiation Efficiency, Impedance Matching, Electromagnetic Band Gap, Gain Improvement.*

1.INTRODUCTION

Due to the quick expansion of wireless communication networks, there is a growing need for small, powerful antennas. Microstrip patch antennas are a popular option because of its small size, low profile, and simplicity of integration. However, surface waves frequently affect MSAs, which can decrease their effectiveness. Antenna performance can be enhanced and surface waves suppressed by using Electromagnetic Bandgap (EBG) structures. This work describes the design and construction of a microstrip patch antenna for wireless communication applications that uses an EBG structure resembling a mushroom. A certain frequency band is used by the suggested antenna, which makes it appropriate for a range of wireless communication devices.

To increase the antenna's gain, decrease side lobes, and boost radiation efficiency, the mushroom-shaped EBG structure is employed. The design and simulation of the proposed antenna are performed using a full-wave electromagnetic simulator. To verify the design, the manufactured antenna is put through testing and measurements. The suggested antenna with EBG structure performs better than the traditional MSA, according to the results.

The proposed antenna is appropriate for contemporary wireless communication systems due to its small size and enhanced functionality. A detailed presentation of the proposed antenna's design and construction is given. This study shows how EBG structures can enhance MSA performance. Numerous wireless communication applications can make use of the suggested antenna. As a result of this study, high-performance antennas for wireless communication systems are being developed.

2. LITERATURE REVIEW

This section explores existing studies, methodologies, and advancements in the field, providing context for the present research endeavor. By critically analyzing prior works, we aim to identify gaps, challenges, and opportunities that inform our approach and contribute to the advancement of antenna design and performance optimization. Through a comprehensive review of scholarly articles, academic papers, and relevant industry reports, this literature survey aims to synthesize and consolidate existing knowledge, providing a theoretical framework and guiding principles.

Luis Inclán-Sánchez in 2024 analyzed and designed the compact stopband filters using coplanar-coupled Electromagnetic Band Gap (EBG) resonators in inverted microstrip gap waveguide technology. The study focused on configurations of mushroom-type elements, where the short-circuit element is positioned at the edge of the resonator patch. A 5-cell EBG filter was designed and fabricated for X-band applications, achieving a maximum rejection level of -35.4 dB with a stopband centered at 9 GHz and a relative fractional bandwidth of 10.6%. The filter exhibited a flat passband with low insertion losses, approximately 1.5 dB across most of the band, demonstrating its potential for integration into low-complexity antenna designs with filtering functionalities.

Mouhsine Harbel and Jamal Zbitou analyzed a novel mushroom-like EBG cell to reduce mutual coupling in a two-element antenna array operating at 28 GHz in 2022. The structure was designed and optimized using CST Microwave Studio. Simulation results revealed an improvement of over 10 dB in isolation. This enhancement was achieved without degrading the antenna's radiation pattern, proving the effectiveness of the EBG approach for high-frequency antenna arrays. In order to place the significance of 2.4 GHz designs in the changing landscape, [1] ,[2] were examined in order to comprehend the fundamental ideas and future development of wireless communication technologies up to 6G. The antenna design's requirement for effective bandwidth utilisation was reinforced by [3],[4], which offered insight into cellular system capacity augmentation strategies and propagation models. [5],[6] provided comprehensive analyses of V2X communication and 5G technologies, highlighting the significance of small, effective antenna systems in contemporary applications.

For microstrip patch antennas, [7] - [10] offered a variety of performance-enhancing techniques, including tuning, material choice, and geometrical adjustments. Supported methods for increasing bandwidth and gain, particularly when using metamaterial loading schemes and partial ground planes [11] & [12].

The mushroom-like EBG implementation used in this study is strongly related to the utilisation of EBG structures for RF energy harvesting, which was informed by [13]. In order to expand operational bandwidth and boost antenna adaptability, [14]&[15] assisted in the exploration of slotted patch and multiband design solutions. [16] investigated the application of cutting-edge materials like as graphene, which led to the notion of incorporating structural improvements (such as EBG) to improve performance.

Theoretical and experimental insights into the impact of EBG structures, especially the mushroom-like EBG, on microstrip antenna performance were offered by [17] & [18], which were immediately pertinent. [19] described in detail how mushroom EBG is used in UWB-MIMO antennas, demonstrating how EBG can be used to suppress surface waves and regulate band-notching. Understanding EBG and FSS configurations for side lobe reduction, triple-band support, and performance optimisation in microstrip antennas was made possible thanks in large part to [20] - [23].

In contrast, this study's suggested mushroom-shaped EBG integrated patch antenna enhances return loss, bandwidth, and impedance matching while directly targeting the 2.4 GHz ISM band. It does this while keeping a small form factor. By using CST Studio Suite for accurate modelling and optimisation, it adheres to current best practices in antenna design and adapts the structure to the unique performance requirements of wireless communication systems. Surface waves are successfully suppressed by the inclusion of EBG structures, improving overall antenna performance and radiation efficiency.

3. PROBLEM STATEMENT

Despite the growing use of microstrip patch antennas in wireless systems, several challenges persist when adapting them to scenarios:

1. **High-Frequency Performance Issues**: Surface wave propagation causes interference, poor gain, and limited bandwidth in antennas intended for 5G communication at millimeter-wave frequencies (e.g., 28 GHz).

2. **Limitations of Conventional Microstrip Patch (MP) Antennas**: Although MP antennas are small, inexpensive, and simple to produce, they have limitations such low radiation efficiency, narrow bandwidth, and dielectric losses.

3. **Surface Wave Suppression**: Antenna performance is reduced by surface waves. In order to increase gain and radiation efficiency, these waves must be suppressed.

4. **Suggested Integration of Mushroom-Like EBG**: To improve bandwidth and gain and reduce surface waves, it is suggested that the MP antenna be equipped with a Mushroom-Like Electromagnetic Band Gap (EBG) structure.

5. **Optimization and Simulation Approach**: In order to improve performance metrics appropriate for 5G wireless communication networks, the study intends to design, simulate, and optimize an MP antenna array as well as a solitary MP antenna utilizing CST software.

Therefore, a small, broadband, frequency-optimized microstrip antenna for 2.4 GHz wireless communication that has consistent performance metrics appropriate for actual WLAN and IoT settings is obviously needed.

4. PROPOSED SYSTEM

The proposed system, which is made especially for 2.4 GHz wireless communication applications, is a small broadband microstrip patch antenna merged with mushroom-like EBG structures. The antenna is designed to be produced at a minimal cost without sacrificing performance. It is made on a FR-4 substrate and consists of a rectangular radiating patch encircled by EBG elements, a substrate, and a ground plane. greater bandwidth, decreased surface wave effects, and greater impedance matching are all benefits of the optimised design.

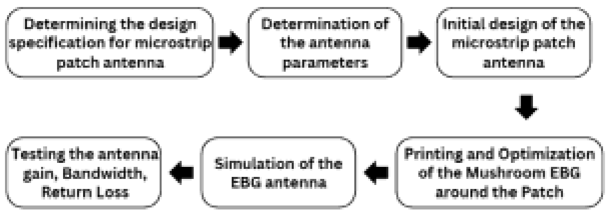


Fig 1. The design steps of the mushroom shaped EBG antenna in a simulation environment.

The conventional MP antenna at an operating frequency of 2.4 GHz is designed as the first phase in the process, as shown in the preceding Fig. 1. This action is taken by selected the functional antenna settings listed in Table 1.

Parameter	Explication
Operating frequency (fo)	2.4 GHz
Dielectric Material	FR4
Relative Permittivity	4.4
Thickness of Dielectric	0.135 mm
Input impedance	50 Ω

Table 1. Selected Parameters for Rectangular MP Antenna

The dielectric substrate properties are selected such that loss is minimized and the antenna operates efficiently at the desired frequency. To this end, the output of this module is a functional microstrip patch antenna design that will subsequently be improved by incorporating the EBG structure.

EBG Structure Design (Mushroom-Like): The third module is the design of the Mushroom-Like EBG structure which will be mounted underneath the microstrip patch antenna. The main procedure involved is: The Mushroom-Like EBG is constructed with a periodic unit-cell structure whose unit cells are designed to damp surface waves at the resonant frequency of the antenna. The building materials of the EBG structure are selected based on their electromagnetic characteristics. These materials can be metallic or dielectric depending on the design requirements.

$$W_{Patch} = \frac{C_o}{2f_r\sqrt{0.5(\epsilon_r + 1)}}$$

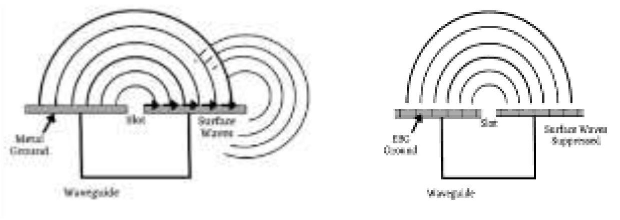
$$\epsilon_{reff} = 0.5\{(\epsilon_r + 1) + (\epsilon_r - 1)\}\left[1 + 12\frac{t}{W_{Patch}}\right]^{-0.5}$$

$$\Delta L = 0.412h\frac{(\epsilon_{reff} + 0.3)\left[\frac{W_{Patch}}{t} + 0.264\right]}{(\epsilon_{reff} - 0.258)\left[\frac{W_{Patch}}{t} + 0.8\right]}$$

$$L_{Patch} = \frac{C_o}{2f_r\sqrt{\epsilon_{reff}}} - 2\Delta L$$

In this structure, the EBG is placed under the micro-strip patch at an optimized distance to improve the performance of the anttena by using the advantages of bandwidth increase, minimization of the stop-wave losses and radiation pattern

improvement. The antenna design and the Mushroom-Like EBG structure in this module is simulated with electromagnetic simulation tool CST Microwave Studio. Simulation is carried out to assess the reflection coefficient and verify the impedance matching.



(a)Without EBG Cells (b)With EBG Cells

Fig 2. MP antenna with and without the EBG cells

In order to reduce interference with other wireless devices and guarantee that the antenna functions effectively within specified frequency ranges, adherence to electromagnetic compatibility (EMC) requirements is essential. Furthermore, the adoption of EBG structures—which improve antenna performance by reducing surface waves and increasing bandwidth—must be assessed in relation to standards for particular applications, including satellite, wireless communication, and Internet of Things systems. To comply with established safety criteria for electromagnetic exposure, the integration of these EBG structures necessitates careful consideration of material

An optimal impedance match allows for the majority of input power to be radiated. Simulations of bandwidth and gain are applied to verify the antenna achieves the necessary design requirements, particularly in wireless communication applications where high bandwidth and gain are necessary. The design is iteratively optimized through parameter adjustment of patch size, substrate type and EBG structure dimensions, to obtain the performance required for the antenna. The objective is to reduce the return loss and to increase the efficiency and radiation pattern.

Mushroom-Like EBG can suppress undesired surface waves and thus enhance radiation pattern and total efficiency. Conventional MPA structures are all designed to be simple, inexpensive and good performance devices in wireless communications. Conventional MPAs are usually based on a single rectangle, a circle or a rectangular patch on a dielectric substrate.In order to illustrate how EBG cells can be thought of as resonant LC, they are typically depicted as lumped elements with an inductor (L) and a capacitor (C).

$$W_{ST} = \frac{2t}{\pi}\left\{\frac{377\,\pi}{2\,Z_o\sqrt{\epsilon_r}} - 1 - ln\left(\frac{377\,\pi}{Z_o\sqrt{\epsilon_r}} - 1\right) + \frac{(\epsilon_r - 1)}{2\,\epsilon_r}\left[ln\left(\frac{377\,\pi}{2\,Z_o\sqrt{\epsilon_r}} - 1\right) + 0.39 - \left(\frac{0.61}{\epsilon_r}\right)\right]\right\}$$

$$L_{ST} = 3.96 \times W_{ST}$$

$$g_{ST-P} = \frac{C_o \times 4.65 \times 10^{-9}}{f_r\sqrt{2\epsilon_{reff}}}$$

$$S_{inset} = \frac{\cos^{-1}\left(\sqrt{\frac{Z_o}{R_{in}}}\right)}{\frac{\pi}{L_{Patch}}}$$

In order to illustrate how EBG cells can be thought of as resonant LC, they are typically depicted as lumped elements with an inductor (L) and a capacitor (C).

$$C = \frac{W \in_r (1 + \in_r)}{\pi} \operatorname{sech}^{-1}\left(\frac{W+g}{W}\right)$$

$$L = 2 \times 10^{-7} h \left[\ln\left(\frac{2h}{r}\right) + 0.5\left(\frac{2r}{h}\right) - 0.75\right]$$

$$f_r = \frac{1}{6.28\sqrt{LC}}$$

The fabricated antenna is then characterized in real-world scenarios by performing a measurement using a network analyzer to determine S11, bandwidth, and gain parameters. In this step, the operating behavior of the antenna is verified and its performance is assessed in compliance with the specification,

5. DESIGN AND SIMULATION OF WITHOUT EBG AND WITH EBG

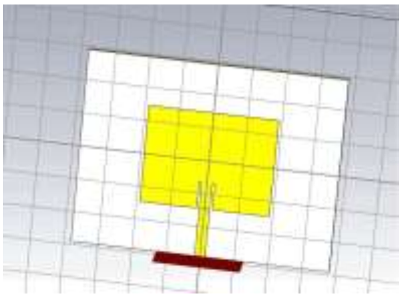


Fig 3. The design of Microstrip Patch Antenna without EBG

The designed for high-frequency wireless communication applications. The yellow area represents the radiating patch, which is responsible for emitting electromagnetic waves.

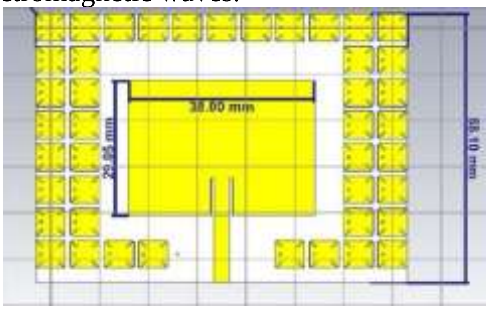


Fig.4 The design of microstrip patch antenna with EBG

Excellent impedance matching is demonstrated at 2.402 GHz, when the return loss (S11) drops to a minimum of -50.89 dB.

6. RESULTS AND DISCUSSIONS

The antenna was simulated, fabricated and tested, with key performance parameters including return loss (S11), bandwidth, gain, and radiation pattern being evaluated. The results demonstrate the impact of the Mushroom-Like EBG on enhancing the antenna's performance for wireless communication applications.

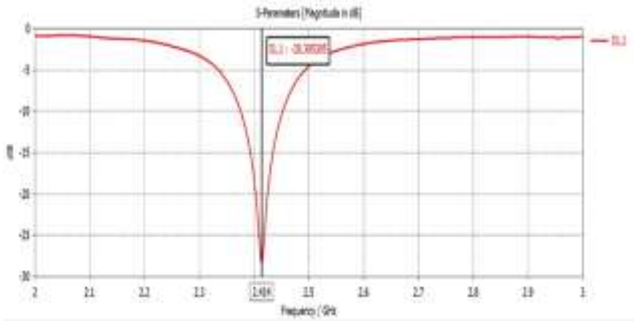


Fig 5(a). Return loss of Microstrip rectangular patch antenna without EBG

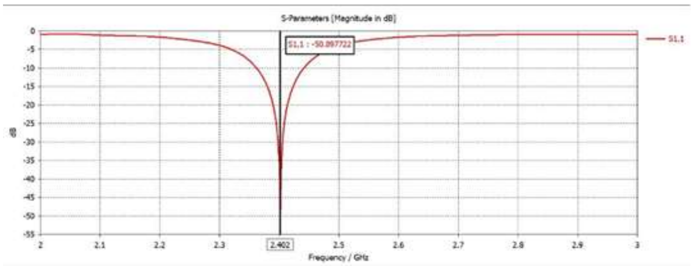


Fig 5(b). Return loss of Microstrip rectangular patch antenna with EBG

The antenna exhibits a strong resonance at 2.414 GHz, with return loss of -28.30 dB, indicating excellent impedance matching and minimal power reflection. Antenna performance with and without the usage of electromagnetic band gap (EBG) structures is compared in the table. Both setups stay compatible with common wireless communication systems by maintaining a 2.4 GHz resonant frequency. However, the incorporation of EBG results in a notable improvement in key performance measures. Better impedance matching and less power reflection are indicated by the return loss improving from -28.30 dB to -50.89 dB.

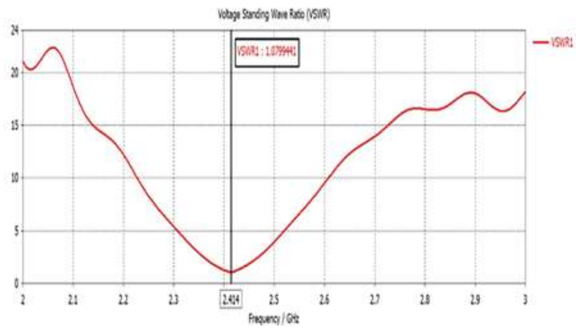


Fig 6(a). VSWR of Microstrip rectangular patch antenna without EBG

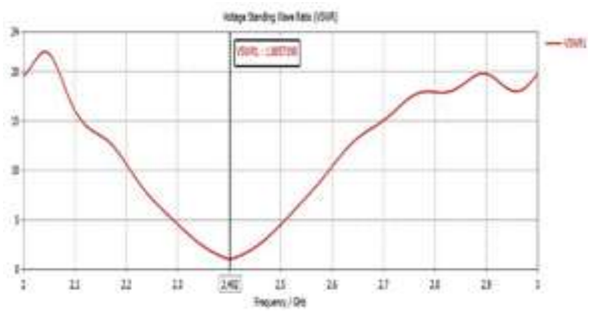


Fig 6(b). VSWR of Microstrip rectangular patch antenna with EBG

This improvement is further supported by the Voltage Standing Wave Ratio (VSWR), which decreases from 1.079, getting closer to 1.005 which is quite near to the optimal value of 1. Additionally, bandwidth increases significantly from 79.92 MHz to 110 MHz, indicating that the EBG structure permits a greater frequency range for effective functioning.

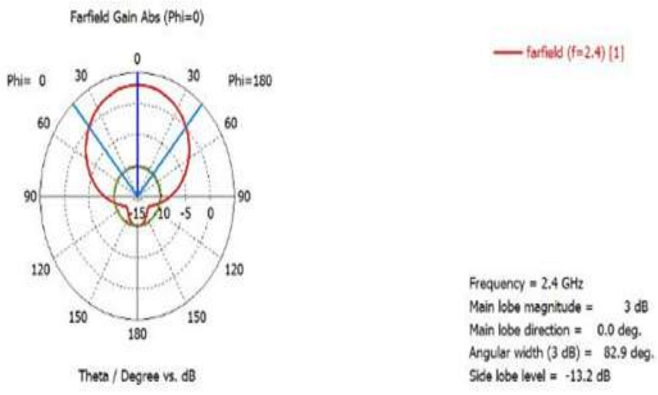


Fig 7. (a) 3D gain Microstrip rectangular patch antenna with EBG

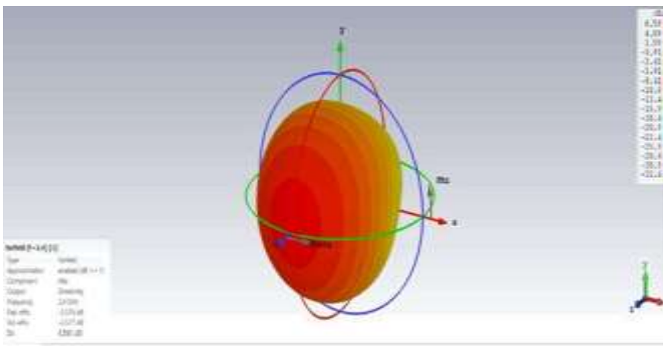


Fig 7. (b) Radiation pattern of the antenna with EBG

A concentrated beam with improved directional performance over an isotropic radiator is indicated by the simulated directivity of 6.590 dBi.The normalized gain pattern in the phi = 0° plane is shown by the red curve. With a peak gain of 6.590 dB and a center of 0°, the primary lobe exhibits significant directional radiation. Table 2. Shows the parameters for comparing without EBG and with EBG.

PERFORMANCE	WITHOUT EBG	WITH EBG
ResonantFrequency	2.4 GHz	2.4 GHz
Return Loss	-28.30db	-50.89 dB
VSWR	1.079	1.005
Bandwidth	79.92 MHz	110 MHz
Gain	2.09 dBi	6.59 dBi

Table 2. Parameters for without EBG and with EBG

Additionally, stronger signal transmission and reception are shown by an improvement in antenna gain from 2.09 dBi to 6.59 dBi. Together, these enhancements show how well EBG structures work to improve antenna performance by reducing signal losses, strengthening gain, and improving impedance matching.

7. CONCLUSION AND FUTURE RESEARCH DIRECTIONS

This paper used CST Studio Suite to effectively design and optimise a small microstrip patch antenna with mushroom-like Electromagnetic Band Gap (EBG) structures for 2.4 GHz wireless communication applications. The antenna, which was built on a cheap FR-4 substrate, demonstrated good impedance matching and broadband performance with a return loss of -50.8 dB, a VSWR of 1.005 at 2.414 GHz, and a bandwidth of 110 MHz. Surface waves were successfully reduced by the addition of EBG structures, improving radiation efficiency and overall antenna performance. These findings support the appropriateness of the suggested design for contemporary wireless systems, such as WLAN and Internet of Things applications, where dependability, efficiency, and small size are crucial.

While the proposed design meets current requirements, future enhancements may include:

- **Advanced EBG Designs:** Explore novel EBG structures for further performance enhancement.
- **Multi-Band Operation:** Design antennas supporting multiple frequency bands for diverse applications.
- **Miniaturization Techniques:** Optimize EBG and patch designs for compact, high-performance antennas.
- **Metamaterial Integration:** Investigate the use of metamaterials to achieve even higher gain and bandwidth.
- **Machine Learning Optimization:** Apply AI techniques for automated antenna design and performance optimization.

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