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Design and Analysis of Compact Microstrip Patch Antenna for WLAN Applications with EBG Structure.

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ABSTRACT
In this work, the design and simulation of a 6 GHz microstrip patch antenna integrated with an Electromagnetic Band-Gap (EBG) structure are presented for enhanced resonance characteristics. The antenna is developed on FR-4 substrate (εr = 4.3, h = 1.6 mm), selected for its low fabrication cost and being apt for high-frequency PCB-based RF applications. A rectangular patch is centrally placed, surrounded by periodic EBG cells acting as a high-impedance surface that reduces surface-wave propagation to improve electromagnetic confinement around the radiator.

The antenna resonates at 6 GHz, and the return loss has improved from −13.04 dB (without EBG) to −18.77 dB with EBG, proving better impedance matching at the frequency of operation. Minimum VSWR is also reduced from 1.57 to 1.26; thus, proving the EBG effectiveness to enhance the signal coupling and radiation performance.

Results show that the loaded EBG enhances the antenna performance with a compact planar footprint that is adequate for GHz-range wireless modules, Wi-Fi 6E, low-range radar, IoT nodes, and emerging high-frequency communication systems.

Keywords: EBG, WiFi, WLAN, VSWR, CST, FR4.
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1. INTRODUCTION:

reduce wave propagation in the substrate plane, hence improving return-loss and better radiation behaviour.

The motivation behind this work is to analyze and demonstrate performance enhancement of a 6 GHz FR-4 microstrip antenna when embedded with EBG cells. The effect of EBG loading is evaluated in terms of S11, VSWR and impedance stability, comparing results with a non-EBG baseline structure as discussed in recent literature [11]–[15].

SAR can be calculated by the following formula: = (1) Where σ is the electrical conductivity (S/m), ρ is tissue density, E is the (R.M.S) root mean square of amplitude of induced electric field. (V/m)[5][14].

2. ANTENNA DESIGN

The basic geometry of the proposed patch antenna is depicted in Fig. 1. The top layer is the radiating patch (copper), backed by a polyester wearable substrate. The substrate is grounded using a copper layer.

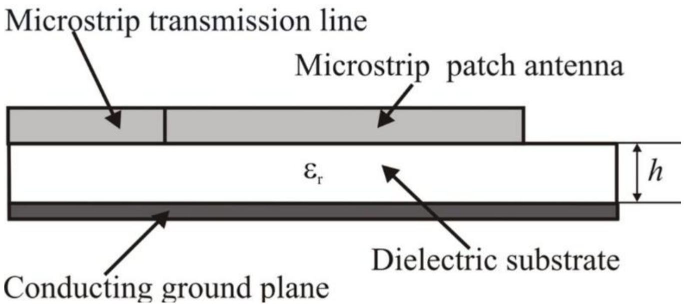

Fig 2.1 Side view of the Rectangular Microstrip Patch Antenna

The following equations are used to calculate the patch antenna dimensions [1]. The width (W) and length (L) of the patch antenna are calculated using:

Patch Width (W)

$$W = (c / (2 \cdot f_r)) \cdot \sqrt{2 / (\varepsilon_r + 1)}$$

Patch Length (L)

$$L = (c / (2 \cdot f_r \cdot \sqrt{\varepsilon\_eff})) - 2\Delta L$$

Effective Dielectric Constant (ε_eff)

$$\varepsilon\_eff = (\varepsilon_r + 1)/2 + (\varepsilon_r - 1)/2 \cdot [1 / \sqrt{1 + 12h/W}]$$

Where h is height of substrate and is effective dielectric constant of the substrate.

Length Extension (ΔL)

$\Delta L = 0.4h \cdot ((\varepsilon_{eff} + 0.3) \cdot (W/h + 0.27)) / ((\varepsilon_{eff} - 0.26) \cdot (W/h + 0.8))$

The proposed antenna operates at 6 GHz, implemented on FR-4 substrate due to its availability, durability, low cost, and stable dielectric behaviour for microwave frequencies. The antenna consists of a rectangular radiating patch which is excited by a microstrip line, while the ground plane is on the bottom layer. To enhance performance, an EBG boundary around the patch creates a suppression region for surface waves to improve impedance matching and return loss response.

The physical dimensions of the structure, selected after parametric optimization, are such that strong resonance is obtained at 6 GHz. The finalized design parameters are:

Ws = 25 mm, Ls = 25 mm, W = 13.85 mm, L = 11.05 mm, We = 3 mm, Le = 3 mm, g = 0.3 mm, r = 0.3 mm, h = 1.6 mm, t = 0.35 mm.

These values are derived using the standard microstrip patch antenna design equations for an effective dielectric constant and length extension, and further tuned through CST simulation until the minimum return-loss depth aligns with the target resonance.

A. EBG Design

EBG Unit consists of periodic square-shaped metallic cells implemented around the patch. Every unit cell comprises a via of 0.3 mm radius that connects the upper metal surface to the ground plane. This periodic structure behaves as a high-impedance electromagnetic band-gap surface that suppresses the lateral substrate waves and confines the radiated field above the patch. Position, periodicity, and number of EBG units are optimized to form a stable stop-band region around 6 GHz. To calculate the dimensions of the unit cell at the resonant frequency (fr)the following equations are used [8, 10].

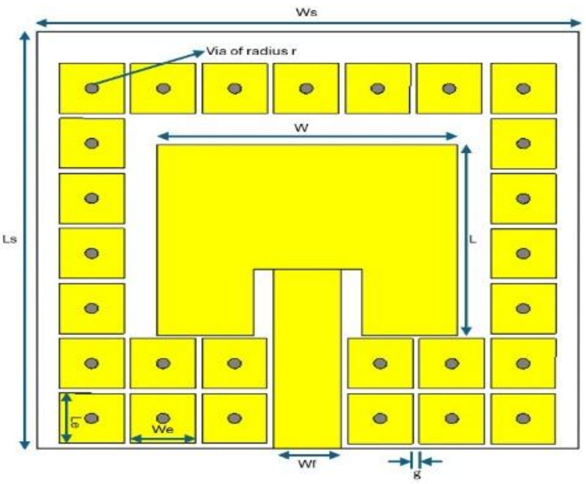

Fig 2.2 Top view of the Rectangular Microstrip Patch Antenna with EBG

III. SIMULATION AND RESULTS

The antenna was simulated using CST Microwave Studio to see how adding the EBG structure impacts its performance. To clearly understand the improvement, four important results are presented:

Return-loss without EBG, Return-loss with EBG, VSWR without EBG, and VSWR with EBG.

Each plot shows the behaviour of the antenna at 6 GHz, which is the target operating frequency. The following sections explain each outcome in a clear and descriptive manner.

Return Loss Without EBG

The return-loss curve of the antenna without any EBG shows that the antenna resonates at 6.0 GHz, with a minimum S11 value of -13.04 dB. This means the antenna can radiate at the desired frequency, but the impedance matching is only moderate. A return-loss of around -13 dB indicates that some of the signal fed into the antenna reflects back instead of being radiated.

Moreover, the -10 dB bandwidth is quite narrow. This suggests that the antenna becomes sensitive to small frequency shifts. This behaviour is typical of simple patch antennas that lack surface-wave suppression.

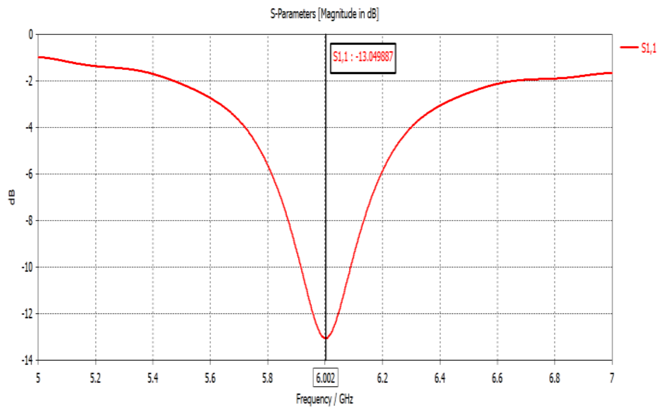

Fig 3.1 Return Loss without EBG

Return Loss With EBG

After surrounding the patch with EBG unit cells, a noticeable improvement is observed. The minimum S11 value drops to −18.77 dB, showing that the antenna now accepts more power at 6 GHz with less reflection.

The bandwidth around the resonance also becomes broader, extending roughly from 5.88 GHz to 6.11 GHz. This indicates that the EBG structure is effectively suppressing unwanted surface waves and stabilizing the electromagnetic environment around the patch.

The deeper return-loss curve confirms that the EBG helps the antenna achieve stronger and more focused resonance at the target frequency.

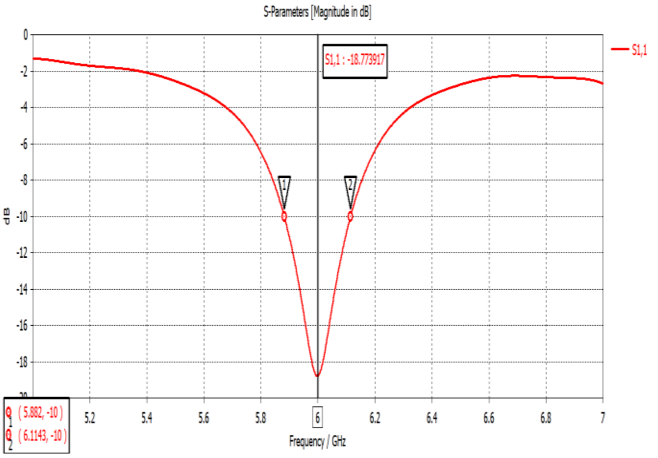

Fig 3.2 Return Loss with EBG

VSWR Without EBG

The VSWR plot of the antenna without EBG shows a minimum value of 1.57 at 6 GHz. A VSWR close to 1 is ideal because it means nearly all the power from the feed goes to the antenna. However, a value of 1.57 indicates that some power is still being reflected. The shape of the VSWR curve is steep, which means the antenna has a narrow operating range and can quickly lose its match if the frequency changes slightly. This again shows the limitations of a conventional patch antenna without improvements.

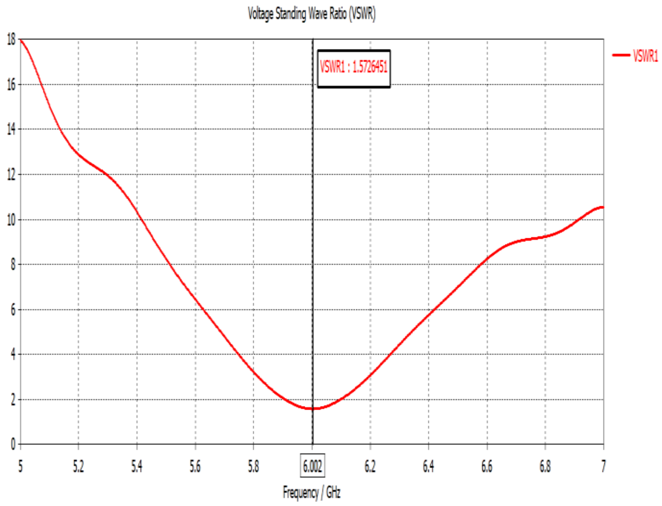

Fig 3.3 VSWR without EBG

VSWR With EBG

When the EBG structure is introduced, the VSWR improves significantly to 1.26 at 6 GHz. This shows that the antenna is much better matched to the feed network and can efficiently radiate the input signal.

The curve becomes smoother and more stable around the resonance point, indicating that the antenna maintains good matching over a slightly wider frequency range. This smoother behaviour is a direct result of the EBG reducing surface waves and improving energy confinement, which ultimately leads to a more controlled electromagnetic response.

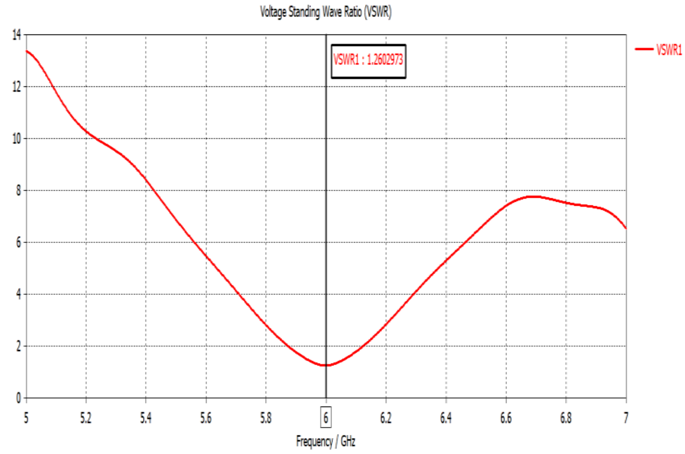

Fig 3.4 VSWR with EBG

Overall Performance Interpretation

The combined improvements from S11 and VSWR clearly demonstrate the benefit of integrating the EBG structure. The EBG-loaded antenna radiates more efficiently, has better impedance matching, and operates more reliably

Parameter	Without EBG	With EBG
Return Loss (S11)	−13.04 dB	−18.77 dB
VSWR	1.57	1.26
Bandwidth	Narrow	5.88–6.11 GHz

3. CONCLUSION

In this project, we designed and studied a compact microstrip patch antenna that operates at 6GHz on an FR-4 substrate. To improve the performance of a typical microstrip patch antenna, we introduced an Electromagnetic Band-Gap (EBG) structure around it. The main goal of adding these EBG cells is to reduce surface-wave effects and achieve better impedance matching and stable operation at the desired frequency.

From the simulation results, it is clear that the EBG structure influences the antenna's behavior. The return loss and VSWR for the basic antenna without the EBG structure are -13.04 dB and 1.57, respectively. This shows moderate impedance matching. After adding the EBG structure, the return loss improved to -18.77 dB and the VSWR dropped to 1.26. This indicates better impedance transfer and resonance characteristics. The operating band will also widen slightly.

Overall, we can see that an EBG-integrated antenna offers several advantages over traditional designs. These include better impedance matching, reduced reflected signals, and more stable performance. Given these improvements, this new solution can be a promising option for various 6E wireless communications, Wi-Fi 6E communications, short-range radar modules, IoT devices, and RFID-based communication modules. Several concepts based on the research findings will be explored and implemented.

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