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Realization of Different-Shaped Electromagnetic Band Gap Antennas for Wi-Fi Applications

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Abstract: The primary objective of this paper is to conduct a comparative analysis of diverse Electromagnetic Band Gap (EBG) antennas in terms of their suitability for Wi-Fi applications operating at 5 GHz. Wi-Fi primarily operates within the 2.4 GHz and 5 GHz frequency bands, with the 5 GHz band offering higher data rates and reduced interference compared to the 2.4 GHz band. Furthermore, its larger number of available channels makes it an optimal choice for environments with high user density. The antennas in this study are designed with dimensions of 28.11x32.40x1.6 mm^3 (length x width x height) using RT/Duroid 5880 substrate, which has a thickness of 1.6 mm and a relative permittivity (εr) of 2.2. The integration of Electromagnetic Band Gap structures in antenna designs has gained substantial attention due to their unique properties that enhance antenna performance characteristics. The paper presents sixteen distinct EBG antennas, all designed using CST software. These antennas incorporate various EBG shapes, such as Fork, L-shape, C-shape, Hash, and Z-shape, positioned on a rectangular patch and in the ground plane. The study's results reveal that the Hash EBG on the patch offers superior performance compared to other EBG types. As a result, the Hash EBG on the patch, alongside various Z-shaped EBGs on the ground plane, is assessed for different antenna performance parameters, including return loss, radiation patterns, and gain. Finally, a diagonal Z-shaped EBG antenna is designed, simulated, and tested. The antenna return loss at 5.2GHz is –48 dB The proposed antenna achieved a peak gain of 7.3 dB at 5.2GHz. The proposed antenna exhibits omnidirectional properties. The antenna shows an efficiency of 90% at the resonant frequency. The experimentally measured results of the designed diagonal EBG antenna have shown satisfactory agreement and are consistent with the simulated results. The findings of this research contribute to a better understanding of EBG antennas potential for Wi-Fi applications in the 5 GHz frequency band.

Keywords: C-shape, EBG, Fork, Hash, L-shape, Swastik, Z-shaped EBG, Wi-Fi.

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1 Introduction

Electromagnetic Band Gap (EBG) structures have emerged as a significant breakthrough in the field of RF and microwave applications, due to their distinctive properties within specific frequency ranges [1 – 9]. Since 1999, EBG structures have been employed in antennas to enhance their performance by suppressing surface waves. Uncontrolled surface waves can lead to decreased antenna gain and efficiency, as they propagate within the ground plane instead of the free space, thereby degrading the radiation pattern. The development of EBG structures compatible with wireless applications has gained substantial interest among researchers [10 – 19]. In this article to improve the gain and to reduce the surface waves the authors designed and simulated various EBG antennas. By incorporating various EBG structures, the gain was improved significantly. The article outlines efforts to enhance gain and reduce surface waves by designing and simulating various EBG antennas. The incorporation of diverse EBG structures resulted in a significant improvement in gain. The radiation patterns of all the Electromagnetic Band Gap (EBG) antennas showcased excellent performance. The simulation and measurement results show a strong agreement, confirming their reliability. Different shapes of EBG offer unique advantages and functionalities to get good frequency tuning and compact dimensions. In this research different types of EBGs are chosen.

2 Literature Review

Adel Y. I. Ashyap et al. [1] proposed a compact wearable antenna with a miniaturized Electromagnetic Band Gap (EBG) operating at 2.4 GHz. In their work, the authors demonstrated that the proposed EBG antenna has a gain of 7.8 dB with an FBR of 15.5 dB. A comparative study of compact multiband bio-inspired asymmetric microstrip-fed antennas (BioAs-MPAs) is presented by Jeremiah O. et al. [2]. In their study, the authors assess the performance of various bio-inspired shapes and techniques, demonstrating their potential suitability for a range of wireless communication applications, including the ISM band, Bluetooth, Wi-Fi, WiMAX, LTE, etc. Wang and Gao [3] incorporated an artificial magnetic conductor (AMC) structure to enhance the gain for wireless body area network (WBAN) applications. The thin and flexible antenna, designed using meander technology and a polyimide substrate, exhibited significant improvement in gain at both 2.45 GHz and 5.8 GHz frequencies [3]. Zhuo Yang et al. proposed a slit-embedded mushroom electromagnetic bandgap structure (EBG) to suppress the propagation of surface waves between antenna elements [5]. Bahare Mohamadzade Ali [8] introduced a novel approach to reduce mutual coupling in microstrip array antennas by utilizing Minkowski fractal geometry and 1D EBG structures. The proposed technique achieves significant coupling reduction without any loss of gain or complex fabrication processes. Adel Y. I.

Ashyap et al. [9] designed a compact antenna with EBG for medical body area networks. The EBGs reduce the frequency detuning due to the human body and decrease back radiation, improving antenna efficiency. The monopole radiator is etched on a 0.8 mm thick FR-4 substrate with a planar size of 20×30 mm². It operates within two wide operational bandwidths (2.40 – 2.55) GHz and (3.85 – 6.93) GHz, as mentioned in [11]. A dual-port MIMO decagon ring antenna with dual inverted T-shaped radiators has been designed and analyzed for Wi-Fi applications [12]. The antenna unit is built on a 42.5×19.5 mm² FR-4 substrate having a thickness of 0.8 mm. The authors mentioned that the antenna can cover the (5.88 – 7.57) GHz Wi-Fi frequency range, meeting bandwidth needs. The MIMO antenna gives a bandwidth of 30.03%. centered at 6.7 GHz. the authors highlighted that the gain of the antenna remains >4dBi throughout the band of frequencies. Shraddha Habbu et.al [13] created a U-shaped microstrip-fed antenna consisting of mirrored caterpillar-shaped strips and a G-shaped strip on the vertical side. The design yields resonances at 2.5 GHz, 10.31 GHz, 11.89 GHz, and 17.45 GHz. The authors observed that the antenna gain is 2.5 dB efficiency is 75% and the radiation patterns are omnidirectional. Reefat Inum et al. [22] designed a compact and efficient microstrip patch antenna integrated with an Electromagnetic Band Gap (EBG) structure to detect and visualize tumors in the human brain. The authors demonstrated that the proposed imaging algorithm effectively utilizes signals from the circular EBG-loaded patch antenna to reliably identify the presence of tumors within the six-layer human head phantom model. The authors proved that the antenna setup efficiently transmits and receives signals within the specified frequency ranges. Many other researchers used EBG to reduce surface waves and to improve gain [14 – 24].

3 Antenna Design

The design of a rectangular microstrip patch antenna using the inset feed technique involves the use of design equations to determine the necessary dimensions. For this antenna, RT/Duroid substrate 5880 with a thickness of 1.6 mm is utilized, and the dimension of the antenna is calculated using the design equations [21]. The dimension of the antenna is shown in **Table 1**.

Table 1

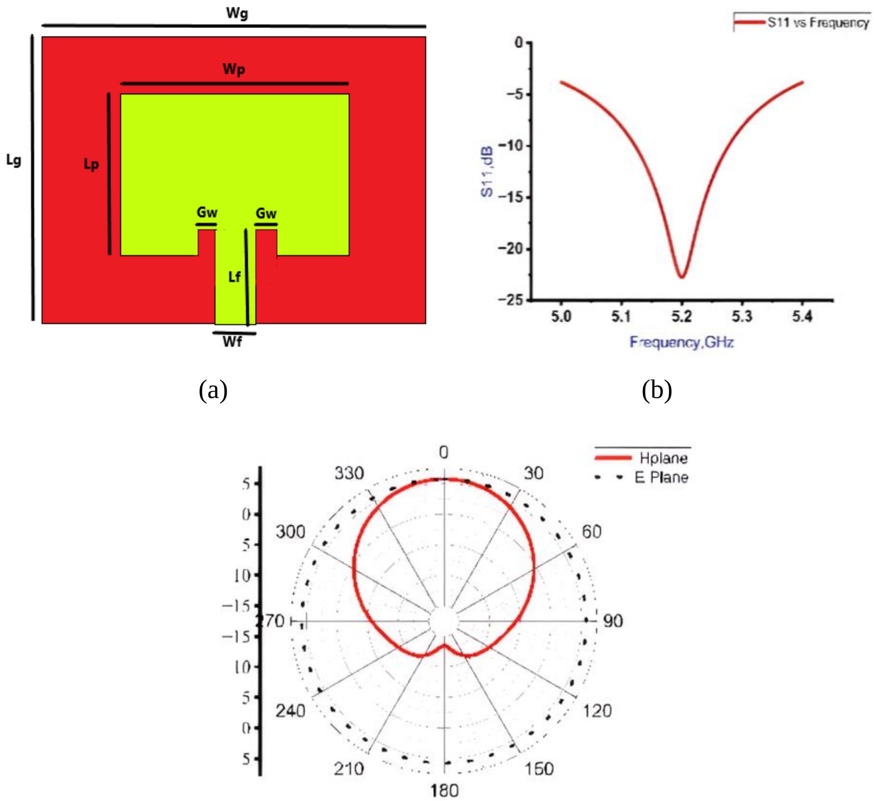
Dimensions of Simple Microstrip patch antenna.

No.	Parameters	Dimensions	No.	Parameters	Dimensions
1.	Ground, substrate width (Wg)	32.4 mm	5.	Patch width (Wp)	22.8l mm
2.	Ground, Substrate length (Lg)	28.11mm	6.	Feed length (FL)	10 mm
3.	Substrate Height (h)	1.6 mm	7.	Feed width (FW)	2.5 mm
4.	Patch length (Lp)	18 mm			

3.1 Design of a simple microstrip patch antenna

Antenna-1: Microstrip antenna without EBG structure

In this section, the patch antenna is designed without incorporating any Electromagnetic Band Gap (EBG) structure on either the ground plane or the patch itself. The antenna design is shown in Fig. 1. The antenna is simulated using CST software. The results indicate that the antenna is resonating at a frequency of 5.2GHz. The results are shown in Fig. 1. The Fundamental configuration exhibits a return loss of –22.7 dB, accompanied by a gain of 5.2 dB and the antenna is giving a good radiation pattern.



(a) (b)

(c)

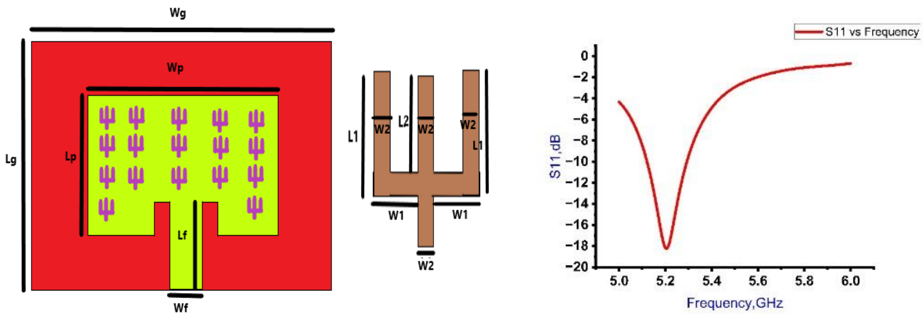
Fig. 1 – (a) *Simple Microstrip patch antenna;* (b) *S11 vs. frequency;* (c) *Radiation Pattern.*

3.2 Design of various EBG structured antennas

In subsequent sections, various EBG structures are introduced, and their implementation is discussed.

Antenna-2: Microstrip Antenna with Fork structure on patch

Subsequently, an EBG patch antenna is constructed by employing fork shaped EBG on the patch. The creation of the fork shaped EBG involves the utilization of precise measurements, whereby the dimensions of the EBG comprise of length (L1) is 1.6mm, width (W1) is 1mm, and width (W2) is 0.6mm thus showcasing its distinctive and intricate geometric composition.



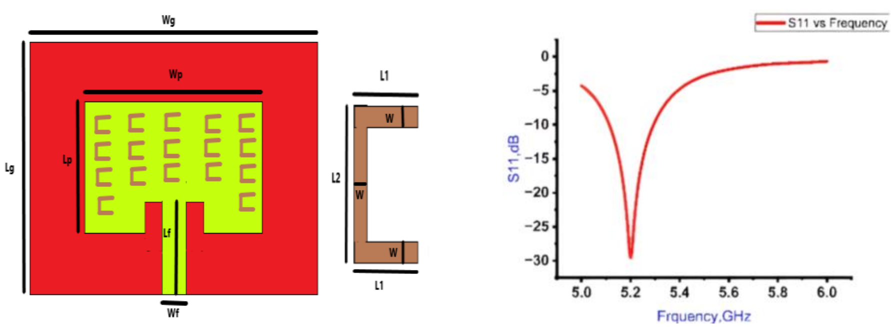
(a) (b)

Fig. 2 – (a) *Antenna with fork EBG on the patch;* (b) *S11 vs. frequency.*

The configuration featuring fork-shaped EBG on the patch yields a return loss of –18 dB, along with a gain of 5.37 dB. This showcases improved design.

Antenna-3: Microstrip patch antenna with C-shaped EBG structure on patch

Next, a microstrip patch antenna is constructed by incorporating C-shaped EBGs onto the patch. The C-shaped EBG demonstrates physical dimensions, featuring a length of 1.5 mm for L1 and 2.6 mm for L2, along with a width of 0.6 mm. This highlights its distinctive structural characteristics.

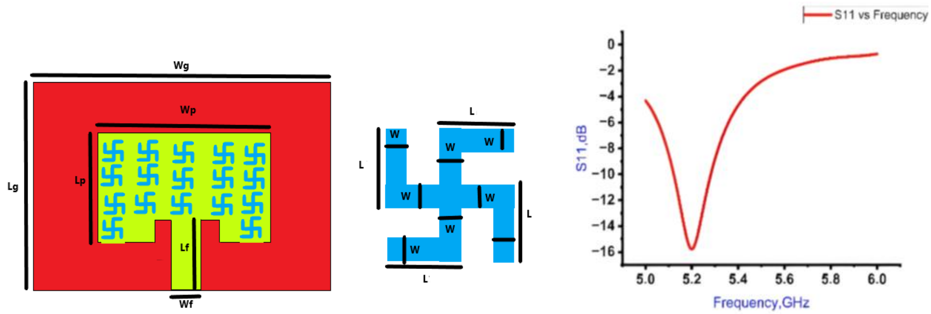


(a) (b)

Fig. 3 – (a) *Antenna with C-shaped EBG on the patch;* (b) *Return loss vs. frequency.*

Antenna-4: Microstrip patch antenna with Swastik EBG structure on patch

Later, a patch antenna is created by positioning the EBGs with a Swastik structure onto the patch. The swastika EBG possesses physical attributes wherein its length (L) is 1.5 mm while its width (W) is 0.6 mm.



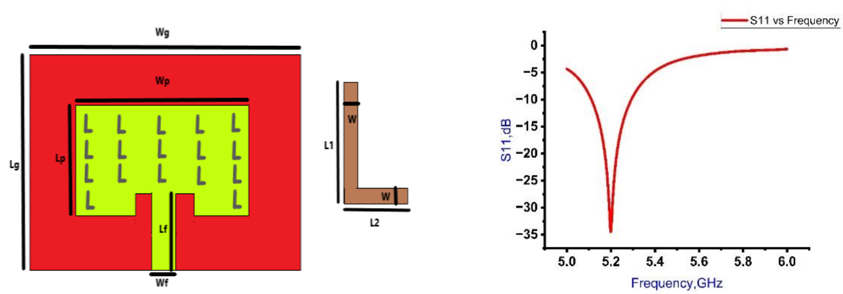
(a) (b)

Fig. 4 – (a) *Antenna with Swastik EBG on patch;* (b) *S11 vs. frequency.*

The design exhibits a return loss of –15 dB, accompanied by a gain of 5.37 dB however, the VSWR value of 1.38. This configuration delivers a superior return loss of –29 dB as compared to its predecessor, while simultaneously offering a gain of 5.36 dB, thereby highlighting its enhanced efficiency.

Antenna-5: Microstrip patch antenna with L-shaped EBG structure on patch

Eventually, a microstrip patch antenna is constructed by integrating L-shaped EBGs onto the patch. The L-shaped EBG represents distinct physical properties, having a length of 2.6 mm for L1 and 1.5 mm for L2, accompanied by a width of 0.6 mm. This emphasizes its unique geometric configuration.



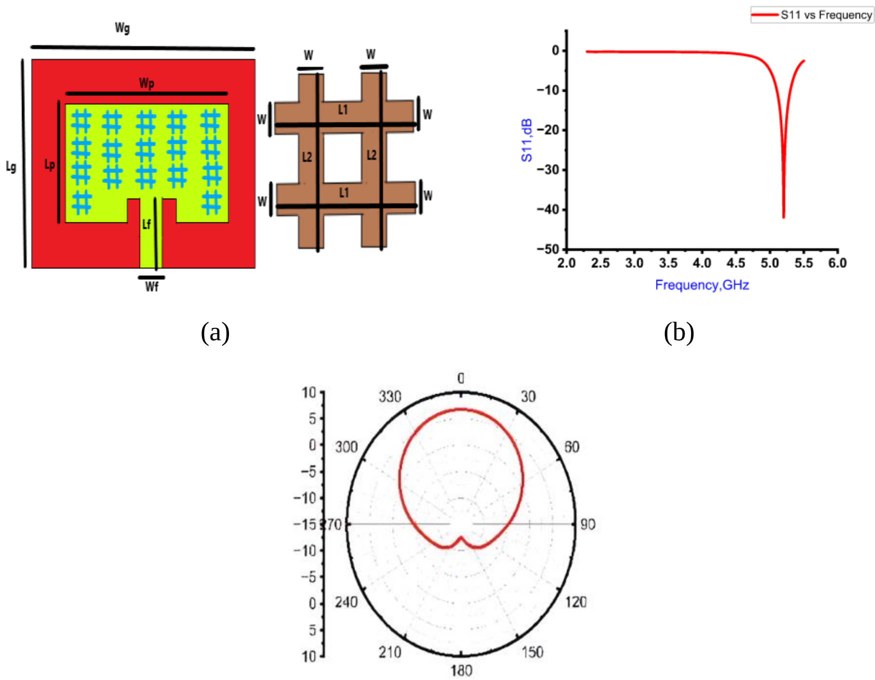
(a) (b)

Fig. 5 – (a) *Antenna with L-shaped EBG on patch;* (b) *S11 vs. frequency.*

Among all the designs, the L-shaped EBG structure produces the second-best result, exhibiting a return loss of –34 dB, accompanied by a gain of 5.37 dB and a VSWR value of 1.03. This highlights its remarkable performance.

Antenna-6: Microstrip patch antenna with Hash EBG structure on patch

Later, a patch antenna is created by utilizing Hash EBG on the patch. The Hash EBG has dimensions of 2 mm for both L1 and L2, accompanied by a width of 0.5 mm, signifying its unique and discernible geometric.



(a) (b)

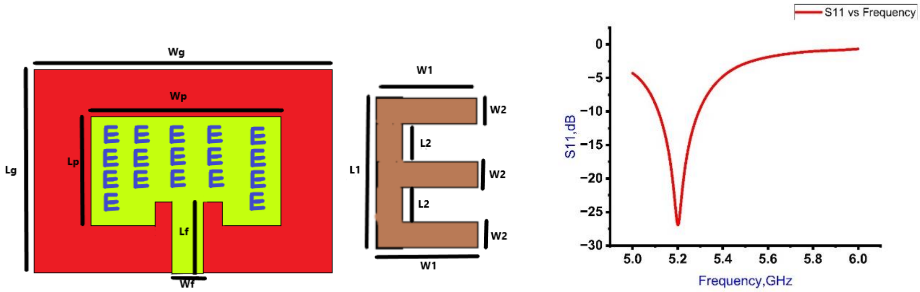
(c)

Fig. 6 – (a) *Antenna with Hash EBG on patch;* (b) *S11 vs. Frequency;* (c) *Radiation Pattern.*

Amongst all the other designs, the Hash EBG exhibits a superior performance, delivering an impressive return loss of –37 dB, accompanied by a gain of 5.82 dB.

Antenna-7: Microstrip patch antenna with E-shaped EBG structure on patch

Finally, the patch antenna is created by incorporating E-shaped EBGs onto the patch. The E-shaped EBG demonstrates detailed physical dimensions, characterized by a length of 2.6 mm for L1 and 0.4 mm for L2, as well as a width of 1.5 mm for w1 and 0.6 mm for w2.



(a) (b)

Fig. 7 – (a) *Antenna with E-shaped EBG on patch;* (b) *S11 vs. frequency.*

This configuration demonstrates a return loss of –26 dB, along with a gain of 5.36 dB and a VSWR value of 1.09, thus highlighting its notable performance.

Based on the data presented, it is evident that the hash structured EBG provides superior gain, return loss, and radiation pattern compared to all other structures. Therefore, the hash EBG structure is used in future designs to enhance the gain and improve the return loss.

3.3 Various structured antenna with/without Hash EBG on patch and z shaped EBG on the ground

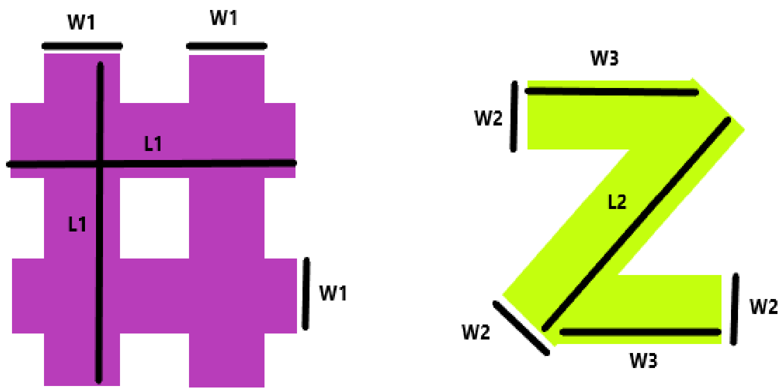
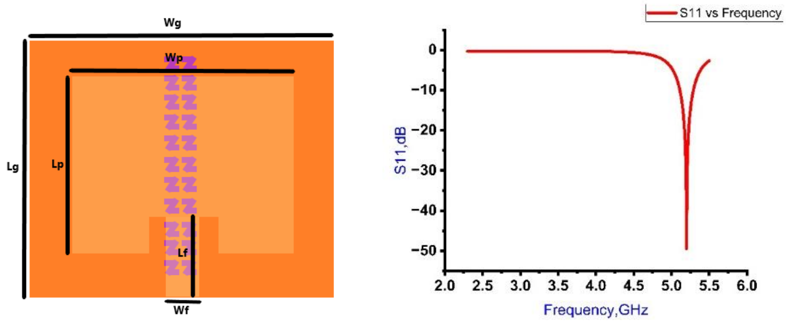


Fig. 8 – (a) *Hash EBG structure;* (b) *Z-shaped EBG.*

In certain designs, the Hash EBG is absent from the patch to facilitate a comparative analysis of outcomes. Conversely, the Z-shaped EBG is carefully arranged on the ground in various configurations. The Hash EBG structure is characterized by dimensions of L1 and L2 measuring 2mm, along with a width of W1 measuring 0.5mm. In contrast, the Z-shaped EBG having the dimensions of L2 is 3mm, and width W2 and W3 are 0.5 mm and 1.5 mm, respectively.

Antenna-8: 1D Z-line EBG antenna

In this design, the EBG is not situated on the patch, rather it is placed on the ground plane.



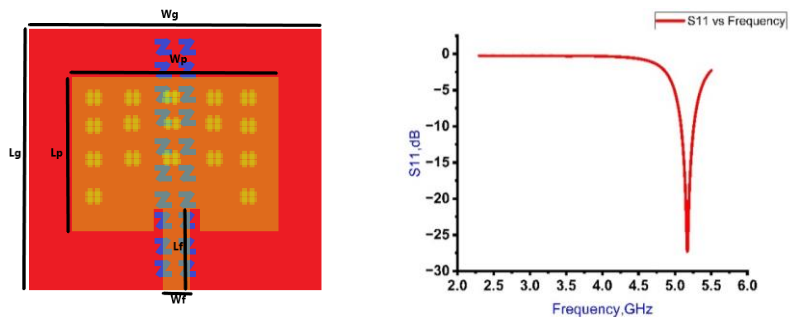
(a) (b)

Fig. 9 – (a) *Microstrip patch antenna with Z-shaped EBG on the ground;* (b) *S11 vs. frequency.*

The analysis reveals that this antenna exhibits favourable return losses of –53 dB and gives a maximum gain of 6.34 dB.

Antenna-9: 2D Hash 1D Z-line antenna

In this design, a pair of straight-line patterned Z-shaped EBG on the ground and Hash EBG on the patch is placed with a 4 mm distance between two Hash EBGs.



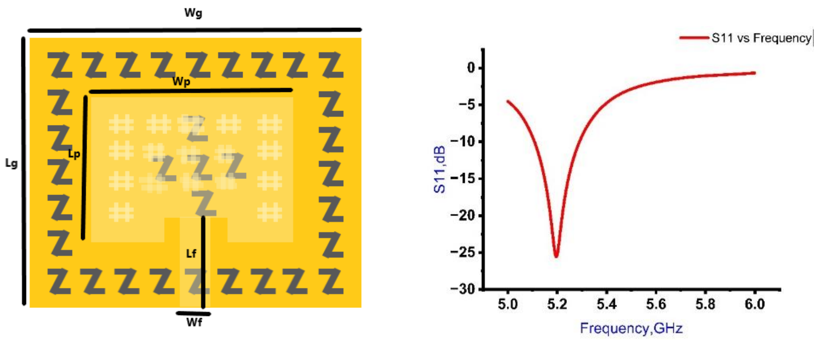
(a) (b)

Fig. 10 – (a) *Antenna with Hash EBG on patch and Z-shaped EBG on ground;* (b) *S11 vs. frequency.*

The analysis reveals that this antenna is exhibiting favourable return losses of –27 dB, having a gain of 6.35 dB.

Antenna-10: Z-loop EBG antenna

In this design, the Hash arrangement is maintained as in the previous design, but the placement of the Z-shaped EBG on the ground plane is altered. The Z-shaped EBG is positioned along the periphery of the ground, and in addition to that, five Z-shaped EBGs are also placed at the center of the ground plane.



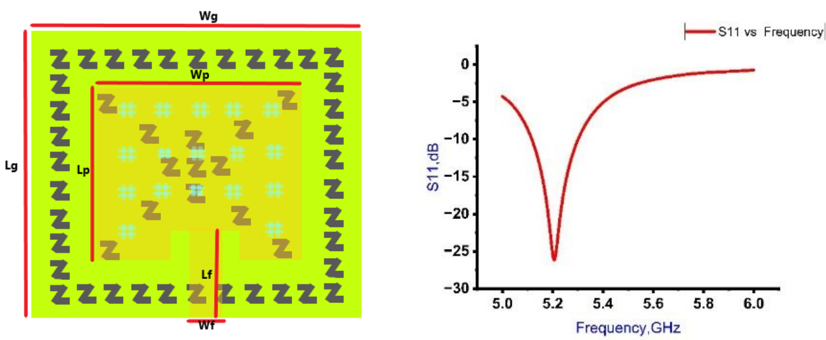
(a) (b)

Fig. 11 – (a) *With Hash EBG on patch and z-shaped on the ground;* (b) *S11 vs. frequency.*

The arrangement has led to a commendable outcome, where the return loss is measured at –25 dB and the gain at 5.2GHz is 6.3 dB.

Antenna-11: 2D diagonal Z-loop antenna

In this design, the Hash configuration remains unaltered, while the Z-shaped EBG on the ground plane is modified by adding an increased number of EBG unit cells compared to the previous design. Additionally, the Z-shaped EBG is positioned diagonally for enhanced performance.



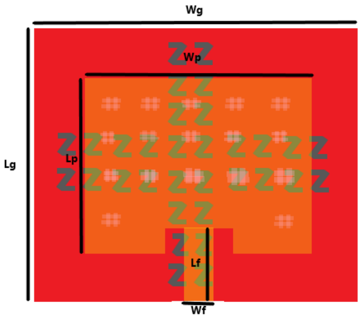
(a) (b)

Fig. 12 – (a) *Hash EBG on the patch and Z-shaped EBG on the ground;* (b) *S11 vs. frequency.*

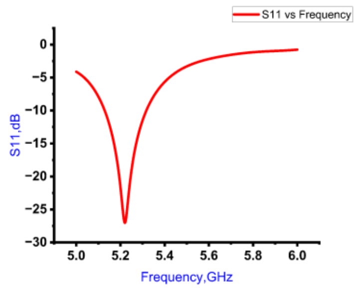
This design yields superior results, with the return losses for this design is 26 dB, and the gain observed at 5.2 GHz is 6.3 dB.

Antenna-12: 2D Hash 1D plus EBG antenna

This design looks very similar to the designs mentioned earlier, except one difference is that the Z-shaped EBGs are arranged in a pattern that looks like a plus sign.



(a)

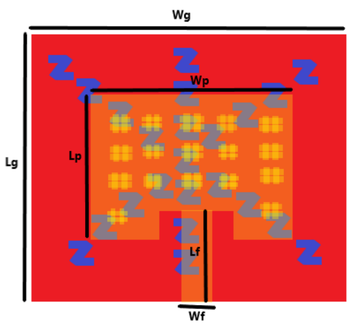


(b)

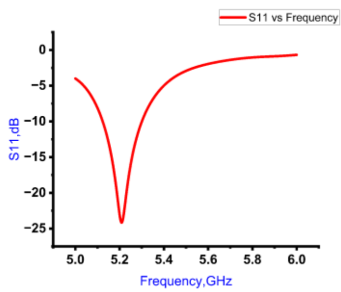
Fig. 13 – (a) *Hash EBG on the patch and Z-shaped EBG on the ground arranged in a plus pattern;* (b) *S11 vs. frequency.*

From Fig. 13b it is observed that the antenna is resonating at 5.2 GHz and the return losses at the resonant frequency is –28 dB and the antenna gives a gain of 6.2 dB at the resonant frequency.

Antenna-13: 2D Hash with diagonal EBG antenna



(a)



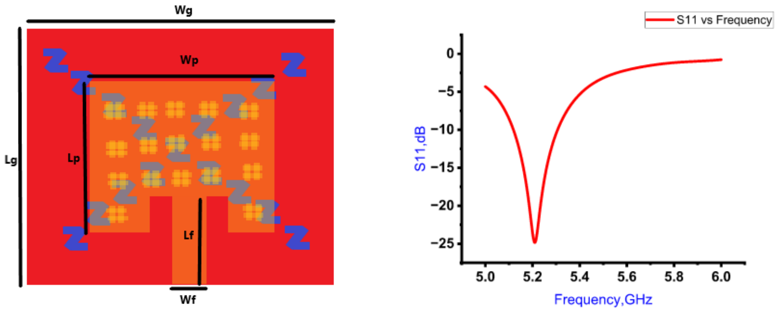
(b)

Fig. 14 – (a) *Hash EBG on the patch and diagonal Z-shaped EBG on the ground;* (b) *S11 vs. frequency.*

This design delivers a lower return loss value of –24dB, when compared with design 12, the return losses of this antenna are less while the gain remains the same as 6.4 dB, like that of antenna 12.

Antenna-14: 2D Hash with Z-line EBG antenna

A microstrip patch antenna featuring a Hash EBG structure on the patch and a diagonally arranged Z-shaped EBG on the ground plane has been designed.

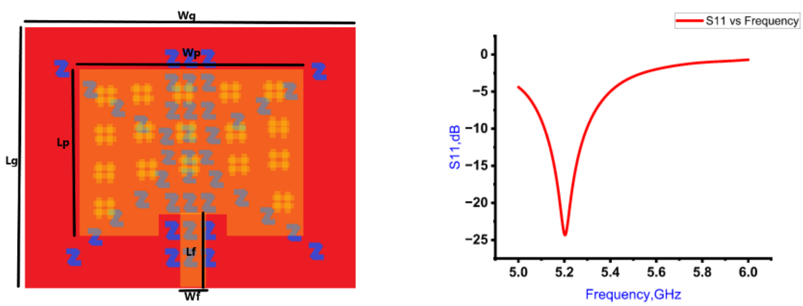


(a) (b)

Fig. 15 – (a) *Hash EBG on the patch and Z-shaped EBG on the ground;* (b) *S11 vs. frequency.*

Antenna-15: 2D Hash 1D lines with diagonal EBG antenna

A microstrip patch antenna has been designed incorporating a Hash EBG on the patch and a 1D line with diagonal Z-shaped EBG on the ground plane. The antenna performance is shown in Fig. 16b.



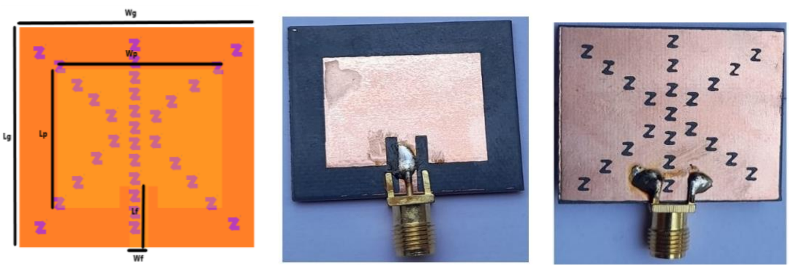
(a) (b)

Fig. 16 – (a) *Hash EBG and Z-shaped EBG;* (b) *S11 vs. frequency.*

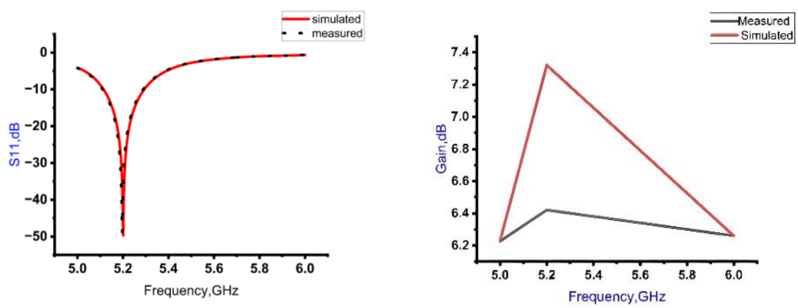
From the results, it is observed that the antenna's performance is not much superior compared to all the other antennas that were reported earlier.

Antenna-16: Diagonal EBG Antenna

Finally, the diagonal EBG antenna consists of Z-shaped EBG, arranged diagonally and vertically as shown in Fig. 17a. It is observed that this design shows superior performance compared to all other antennas mentioned before. The antenna parameters are measured by simulation. It is inferred from the results that the return loss for the antenna is –48 dB and observed a commendable gain of 7.3 dB. The antenna is fabricated, and the fabricated antenna is shown in Fig. 17b and c. The surface current distribution of the antenna is measured by simulation, and it is shown in Fig. 18a. At the boundaries between the different regions of the EBG, there can be reflections and refractions of surface currents. These interactions can cause constructive or destructive interference influencing the current distribution on the antenna. From the surface current graph, it is observed that the surface current is not uniformly distributed. The surface current is maximum on the patch and less on EBG structures. With less surface current on the EBG structure, the antenna's back radiation reduces.

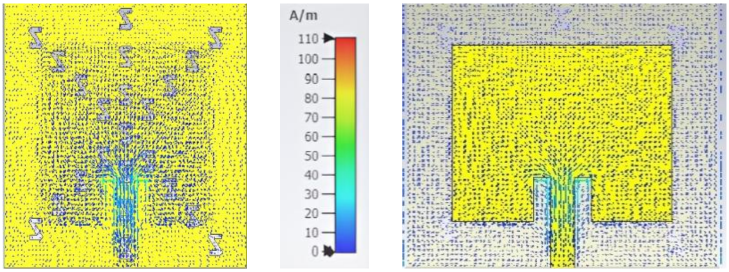


(a) (b) (c)

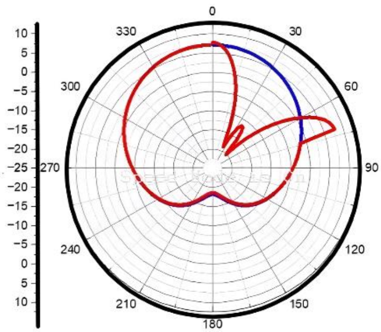


(d) (e)

Fig. 17 – (a) *Structure of Z-shaped diagonal EBG on the ground;*
(b) *Fabricated Diagonal EBG antenna front view;*
(c) *Fabricated Diagonal EBG antenna back view;*
(d) *Comparison of simulated and measured return losses vs. frequency;* (e) *Comparison of Gain.*



(a)



(b)

Fig. 18 – (a) *Surface current distribution;* (b) *Simulated (blue) and measured (red) radiation patterns.*

From the above results, it is observed that the simulated and measured results are in line. Finally, a comparison of all the antennas is done and is reported in **Table 2**.

Table 2
Comparison of Various EBG Antennas.

Type of Antenna	Frequency [GHz]	Gain [dB]	Bandwidth [GHz]	S11 [dB]
1D Z-Line EBG	5.2	6.34	0.1799	–48
2D Hash 1D Z-Line	5.2	6.35	0.2060	–27
Z-Loop EBG	5.2	6.30	0.212	–26
2D Diagonal Z-Loop	5.2	6.30	0.1847	–25
2D Hash 1D Plus EBG	5.2	6.29	0.1885	–27
2D Hash with Diagonal EBG	5.2	6.42	0.1771	–24
2D Hash with Z-Line EBG	5.2	6.10	0.1869	–24
2D Hash 1D Line with Diagonal EBG	5.2	6.33	0.1840	–24
Diagonal EBG	**5.2**	**7.3**	**0.1794**	**–48**

Finally, the proposed antenna is compared with the recently reported antennas mentioned in the literature and it is shown in **Table 3**.

Table 3

Comparison of proposed antennas with recently reported antennas in literature.

Ref.	Dimensions of the antenna [mm]	Resonant frequency [GHz]	Gain [dB]	S11 [dB]
1	33 × 15	2.6, 4.4, 5.5	2.25 / 1.46 / 4.67	–20.26 / –33.05 / –19.8
2	46 × 46 × 2.4	2.4	7.8	–45
3	61.5 × 61.5	2.45 / 5.8	5.67 / 6.89	–28, –41
5	70 × 40	3.25	5.25	–15
6	81 × 81 × 4	2.45	7.3	–35
8	80 × 150	5.6	5.1	–35
11	45 × 30	2.39 – 2.57 3.82 – 6.95	2.65	–25, –35
12	42.5 × 19.5 × 0.8	5.88 – 7.57	4	
13	40 × 40 × 0.8	2.5, 10.31, 11.89, 17.45	2.5	
19	31.68 × 31.02	7.3	6.7	–18
20	27 × 27 × 1.6	4.6	4.1	–30
PW	**32.4 × 28.11 × 1.6**	**5.2**	**7.32**	**–48**

4 Conclusions

Various compact EBG antennas are designed, simulated, and tested. The performance of all antennas is compared. From the results, it is observed that the Diagonal EBG antenna gives better performance characteristics compared to other EBG antennas. The diagonal EBG antenna is designed and simulated, and a physical antenna has been fabricated and tested the proposed Diagonal EBG antenna is compact in size compared to other antennas reported in the literature [2, 3, 5, 6, 9, 11, 12]. The proposed antenna is giving good return losses of –48 at 5.2 GHz and the gain of the antenna is high compared to all other antennas [2, 3, 5, 6, 9, 11, 12]. The proposed antenna achieved a peak gain of 7.3 dB at 5.2 GHz. The proposed antenna exhibits omnidirectional properties. The antenna shows an efficiency of 90% at the resonant frequency. The experimentally measured results of the designed diagonal EBG antenna have shown satisfactory agreement and are consistent with the simulated results. Shrinking the size of EBG antennas while maintaining good performance characteristics is a challenging task. Future work could focus on developing miniaturized compact EBG antenna designs for integration into wearble devices.

5 References

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