Progress In Electromagnetics Research C, Vol. 135, 13–22, 2023

A Novel EBG Dual-Band Antenna Structure for X-Band and WLAN Applications

Loubna Rmili*, Bousselham Samoudi, Adel Asselman, and Sanae Dellaoui

Abstract—This paper presents a novel dual-band dielectric electromagnetic band gap (EBG) antenna that operates in both wireless local area network (WLAN) and X-band satellite applications. The proposed structure comprises new double EBG layers placed on the top face and fed by a coaxial probe. The design and parametric analysis of the band gap structure have been performed using Ansys HFSS simulation software. The measurement results are found in good agreement with the simulation results, indicating that the proposed antenna design is a promising solution for dual-band applications. As a result, we have found significant enhancement in gain up to 8.1 dB and 9.3 dB at both frequencies of 5 GHz and 9.8 GHz.

1. INTRODUCTION

In recent years, the development of telecommunication systems has seen significant advancements. As a result, new technologies are being developed to improve network performance [1]. In the field of antennas, structures composed of a periodic electromagnetic band gap (EBG) have gained popularity due to their wideband capabilities [2], high gain [12], and low cost. However, achieving these characteristics simultaneously is often difficult [3, 4].

Dual-band antennas [17–20] are specifically designed to operate at two distinct frequency bands, allowing for compatibility with multiple communication systems and applications. These antennas address the increasing demand for wireless communication systems that require operation in multiple frequency bands. The design and optimization of dual-band antennas present unique challenges and opportunities, requiring careful consideration of antenna geometry, feeding techniques, and radiation patterns [13, 14].

Dielectric and metallic EBG technologies have a wide range of applications in RF and microwave engineering, including waveguides, filters, cavities, and antennas [5]. EBGs are defined as periodic lattices and can be realized as dielectrics or metals, and composed of two materials or more [16]. This periodicity can exist in 1D [6], 2D [5, 15], or 3D [7], with the latter finding numerous applications. Previous works [1, 8–10] in the field have also involved the use of EBG structures for improving the performance of antennas.

This paper reports a dual-band EBG structure for WLAN and X-band satellite communication applications to enhance the gain, according to the Institute of Electrical and Electronics Engineers (IEEE). The X-band is widely used for radar, civil and military institutions, and weather monitoring [1]. The proposed antenna design is optimized using the High Frequency Structure Simulator (HFSS) software, with the parameters selected to achieve an input impedance of approximately 50 Ω, otherwise, the reflection coefficient below −10 dB at the operating frequency. However, this work presents a new EBG structure that has demonstrated significantly better results in terms of gain compared to previous structures.

Received 20 May 2023, Accepted 8 July 2023, Scheduled 17 July 2023

* Corresponding author: Loubna Rmili (loubna.rmili@etu.uae.ac.ma).
The authors are with the Optics, Material and Systems Team, Faculty of Sciences, Abdelmalek Essaadi University, P.O. Box: 2121, Tetouan, Morocco.

2. ANTENNA CONFIGURATION PROCESS

2.1. Antenna Structure without EBG

The initial phase of the design process involves determining the width and length of the antenna such that it conforms to the specified angular opening θ. The electric E-field at the radiant spot has been observed to be nearly constant across the width of the antenna. Consequently, a direct correlation between the size of the antenna and the $-3\,\text{dB}$ aperture of the radiation lobe in the horizontal plane can be established [11].

$$L_{\text{sub}} = \frac{10^{\frac{D_{db}}{10}} \cdot \lambda_0^2}{0.8\pi^2} \tag{1}$$

$$\theta_{-3\,\text{dB}} = 50.8\,\frac{\lambda}{W_{\text{sub}}} \tag{2}$$

where:

D_{db}: Directivity.

λ_0: Wavelength in vacuum.

The proposed antenna as shown in Figure 1 is fabricated on an FR-4 substrate with a thickness of $h = 1.6\,\text{mm}$, a dielectric permittivity of $\varepsilon_r = 4.4$, and a loss tangent of $\tan\delta = 0.025$. The primary antenna is a $15\,\text{mm} \times 12\,\text{mm}$ rectangular patch fed by a coaxial probe, which is optimized for dual-band operation. The patch element of the antenna is excited using an SMA coaxial connector, with the internal conductor diameter equal to 1.37 mm and the external conductor diameter equal to 6.35 mm. The dimensions of the patch element are calculated and presented in subsequent Table 1. This material is chosen for its low cost and compatibility with other standard printed circuit boards (PCBs).

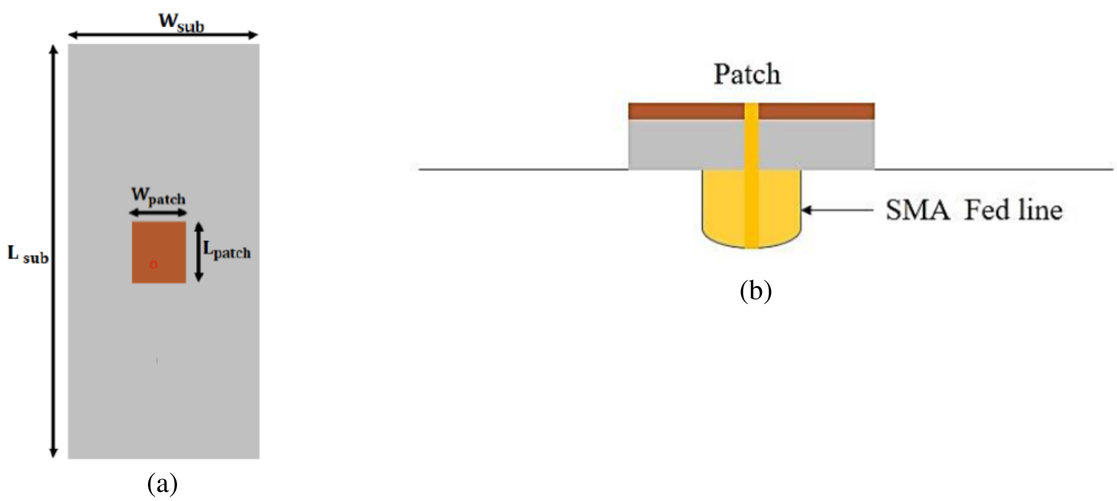


Figure 1. Proposed antenna without EBG, (a) top view, (b) side view.

Table 1. Parameters of the proposed antenna.

Description	Parameter	Value (mm)
Length of Patch	L_{Patch}	15
Width of Patch	W_{Patch}	12
Length of the substrate	L_{sub}	184
Width of the substrate	W_{sub}	50

The proposed antenna is designed to operate in both WLAN and X-band satellite applications. The simulated results of the reflection coefficient S_{11} for the proposed antenna are analyzed and illustrated in Figure 2, and it is observed that the proposed antenna resonates at a frequency of 5 GHz and 9.8 GHz with a coefficient of reflection equal to -17 dB and -13 dB, respectively, indicating that the antenna is well matched for both frequencies. However, while the proposed antenna exhibits a reasonable gain demonstrated in Figure 3 at the operating frequencies 5 GHz and 9.8 GHz about 4.47 dB and 7.47 dB, respectively, it is not sufficient to meet the desired performance specifications. Therefore, it is decided to add an EBG structure to enhance the gain and improve the overall performance of the antenna.

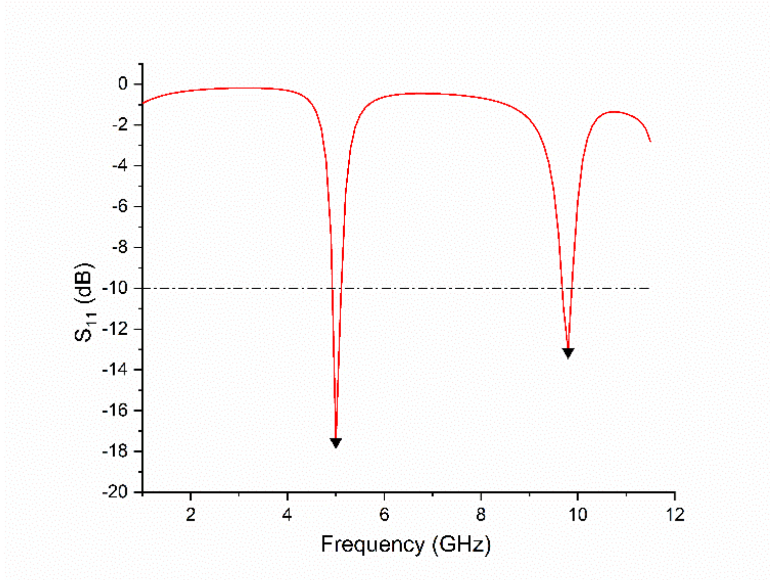
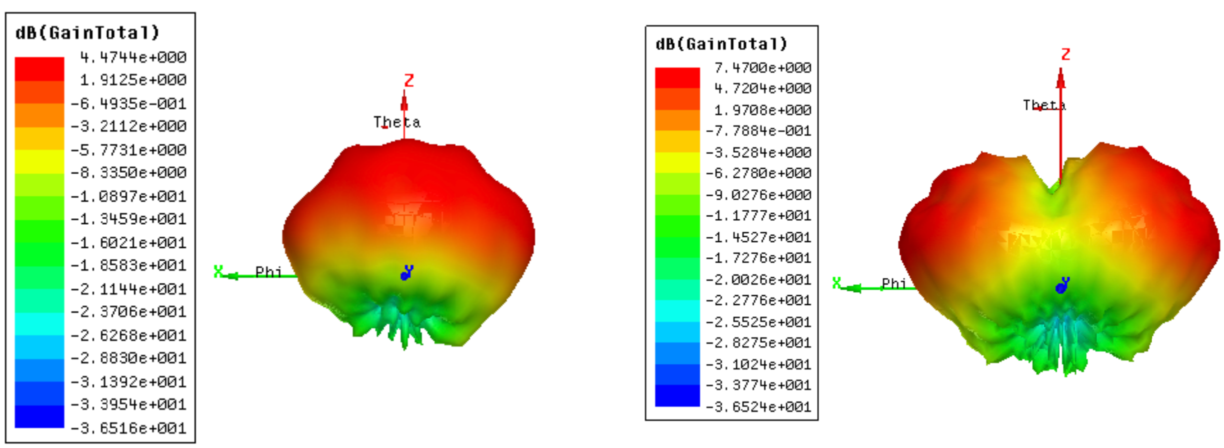


Figure 2. Coefficient reflection S_{11} of the proposed antenna without EBG.



(a) (b)

Figure 3. 3D radiation pattern of the proposed antenna without EBG: (a) 5 GHz, (b) 9.8 GHz.

2.2. Antenna Structure with EBG Rods

In this section, we investigate the impact of incorporating dielectric rods as it appears in Figure 4 on the performance of an antenna. Our goal is to enhance the gain of the antenna through the inclusion of these rods in the design. Our simulations have revealed that the presence of the rods leads to a noteworthy improvement in the gain of the antenna. Furthermore, we have found that the optimal placement of the rods is crucial in achieving maximum gain enhancement. The results demonstrated in

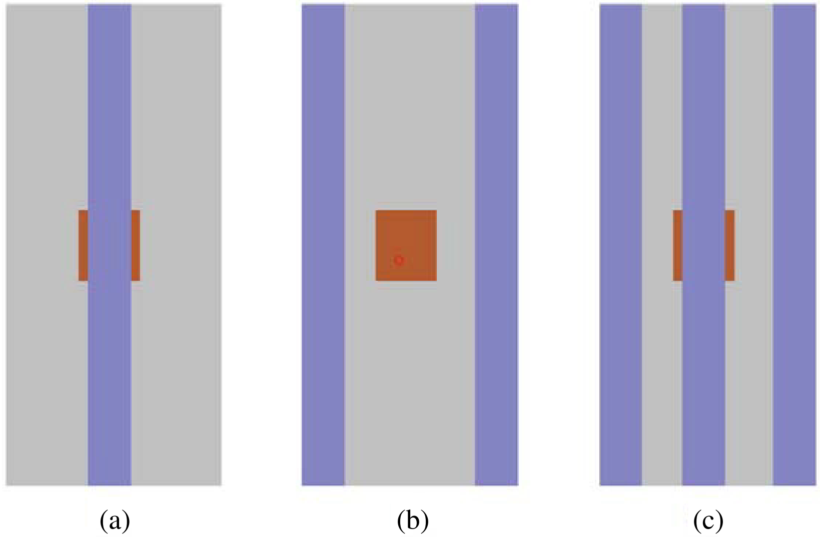


Figure 4. EBG rods with: (a) 1 rod, (b) 2 rods, (c) 3 rods.

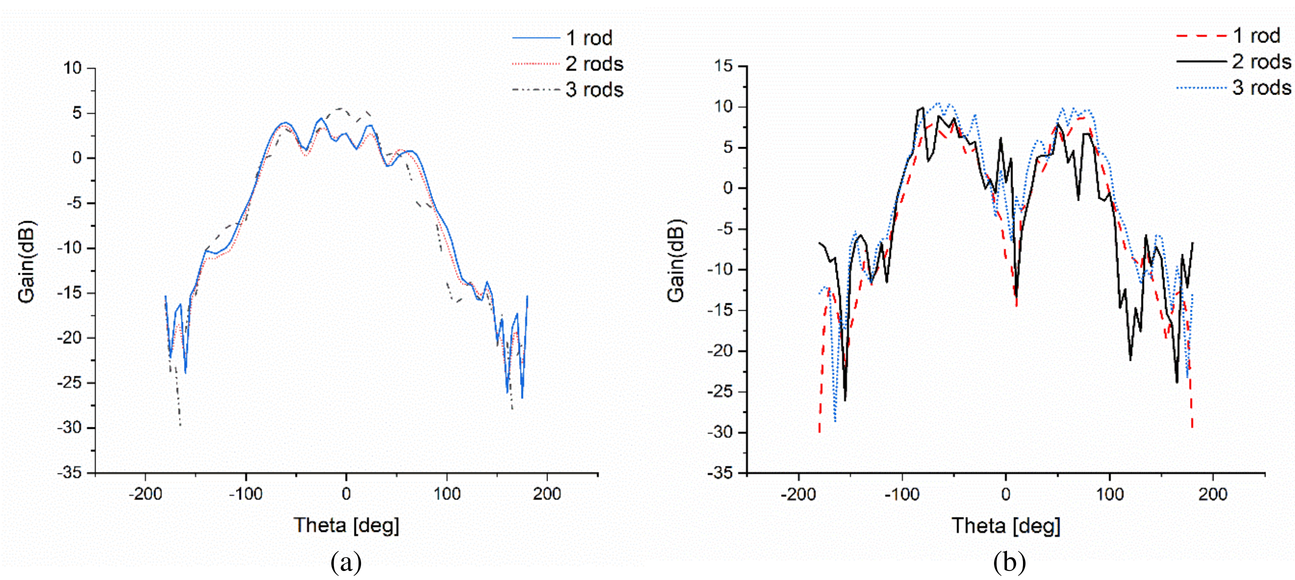


Figure 5. Effect of number of rods on gain for (a) 5 GHz, (b) 9.8 GHz.

Figure 5 present that the use of dielectric rods in combination with EBG could be an effective method for increasing the gain of the antenna while maintaining a compact structure. Additionally, we have found the best results obtained for three rods with 5.63 dB and 8.80 dB for both frequencies 5 GHz and 9.8 GHz. To further improve the performance of the antenna, we propose adding a rectangular box EBG to the design.

2.3. Antenna Structure with Rectangular EBG

The influence of holes on EBG structures has been investigated in this section, and different configurations were proposed and presented in Figure 6. The first two structures, a rectangular EBG without holes and with holes in the middle, both showed a perturbation due to the lack of symmetry in the structure. On the other hand, the EBG structures with double V-shaped holes did not achieved bidirectional results. To overcome these limitations, a new rectangular EBG structure with optimized hole placement on both sides was proposed, which showed a more symmetrical radiation pattern and

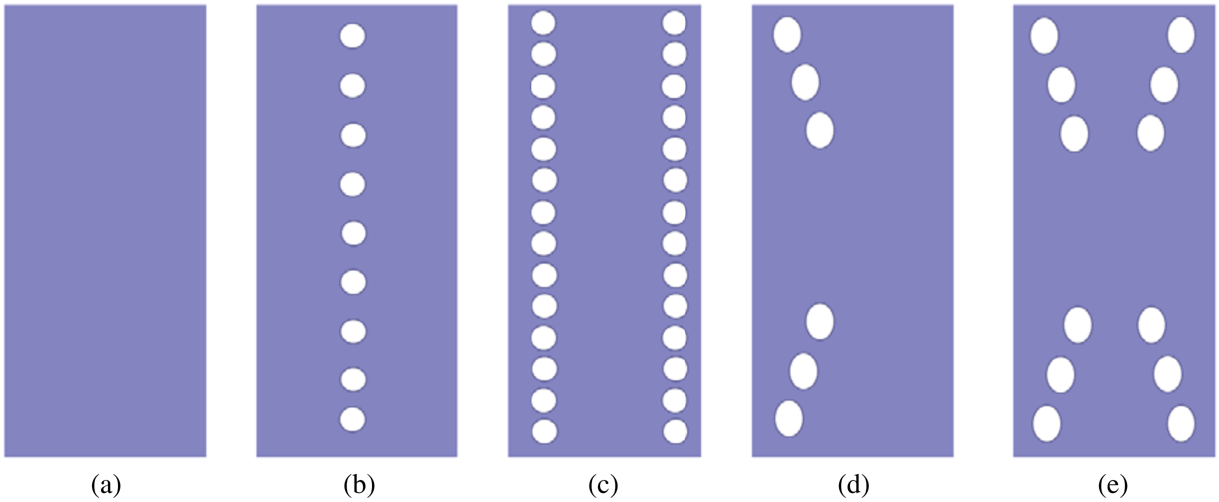


Figure 6. Rectangular EBG: (a) Without holes, (b) with holes in the middle, (c) with straight holes on both sides, (d) proposed structure, (e) with double V shape.

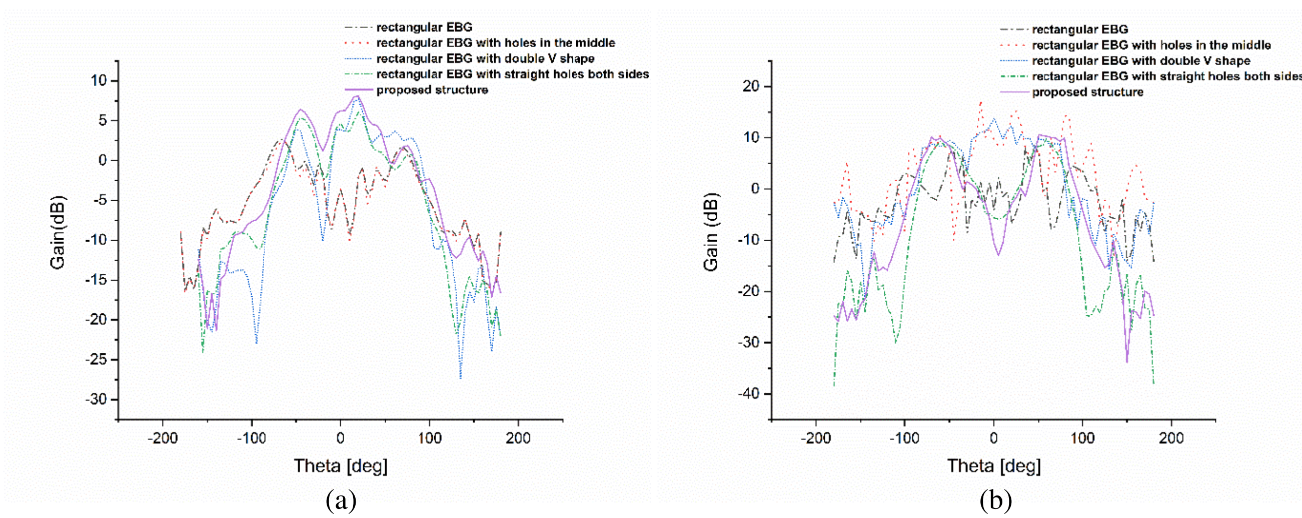


Figure 7. Effect of holes position on gain for (a) 5 GHz, (b) 9.8 GHz.

exhibited satisfactory outcomes. However, it did not exhibit bidirectional behavior similar to that of the proposed EBG structures which achieved gains of 8.1 dB at 5 GHz and 9.3 dB at 9.8 GHz.

The introduction of holes in the EBG structure caused variations in radiation pattern due to changes in the distribution of electric fields and currents. The study suggests that the design of the EBG can be optimized by carefully selecting the position of the holes. Overall, the presence of holes in the EBG structure significantly affects the band gap and propagation properties, as illustrated in Figure 7, and optimal performance can be achieved by considering the position and shape of the holes in the design.

Figure 8 displays the gain over frequency for the different designs, revealing that higher gain has been achieved when using an EBG structure than using rods or without EBG. These results demonstrate the effectiveness of EBGs in enhancing the gain of antennas.

2.4. Optimal Antenna Structure

The optimal design consists of two distinct layers of Teflon as illustrated in Figure 9. The first layer comprises triple rods, while the second layer is a rectangular dielectric with holes on both sides.

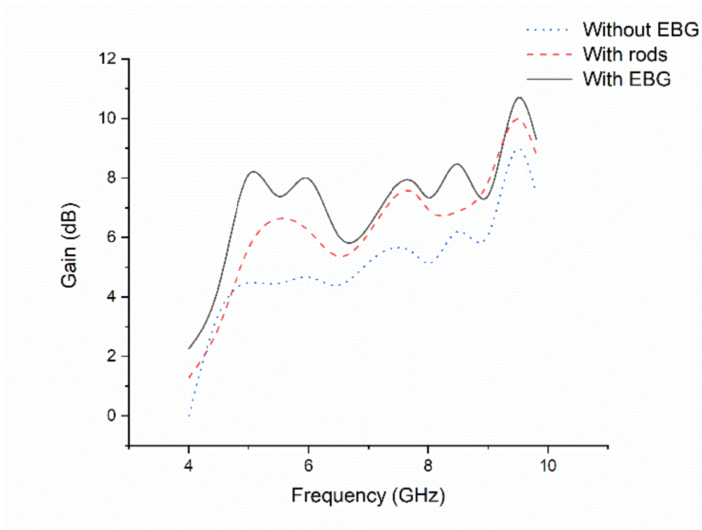


Figure 8. Gain over frequency.

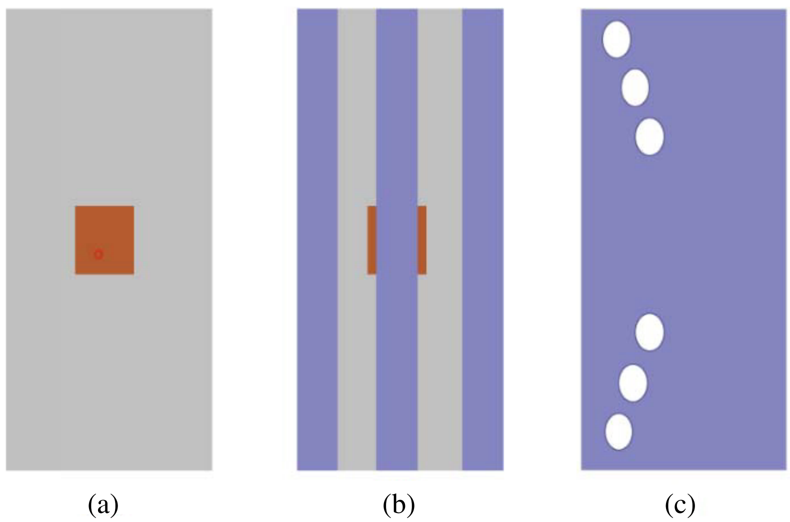


Figure 9. (a) First layer of antenna structure, (b) middle layer composed of EBG rods, (c) top layer composed with the rectangular EBG.

Material selection was carefully considered ensuring that the proposed structure did not introduce any perturbations to the antenna design. After a thorough examination of various options, it was determined that ROHACELL foam is the most appropriate material for this purpose, as it exhibits properties that are substantially similar to those of air. The proposed antenna structure was designed in HFSS simulator and presented in Figure 10.

3. EXPERIMENT VALIDATION AND DISCUSSION

The antenna prototype as shown in Figure 11 was conducted in the LASIT laboratory (Information Systems and Telecommunication Laboratory) using a ROHDE & SCHWARZ ZVB20 Vector Network Analyzer (VNA) as illustrated in Figure 12.

The simulated and measured results of the reflection coefficients S_{11} for the proposed antenna are illustrated in Figure 13. The measured curve shows good agreement with the expected performance, confirming resonance of the cavity at the intended frequencies of 5 GHz and 9.8 GHz. Therefore, it can be concluded that the results obtained from both simulation and measurement are compatible and

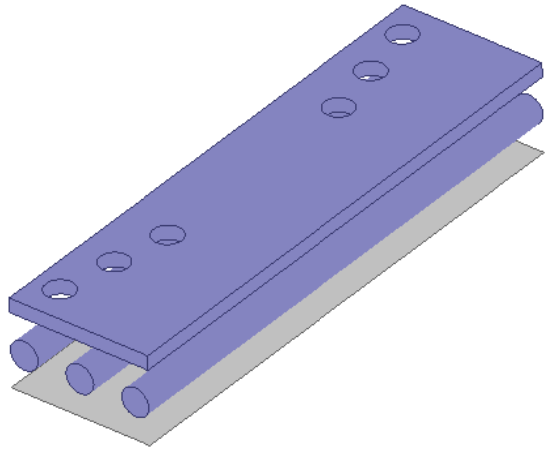


Figure 10. Proposed antenna structure.

Figure 11. Fabricated prototype.

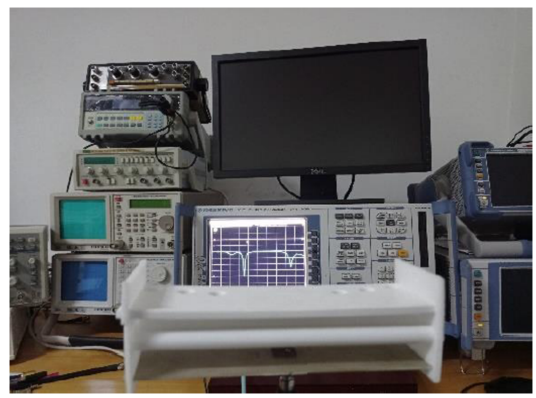


Figure 12. Proposed antenna under the test.

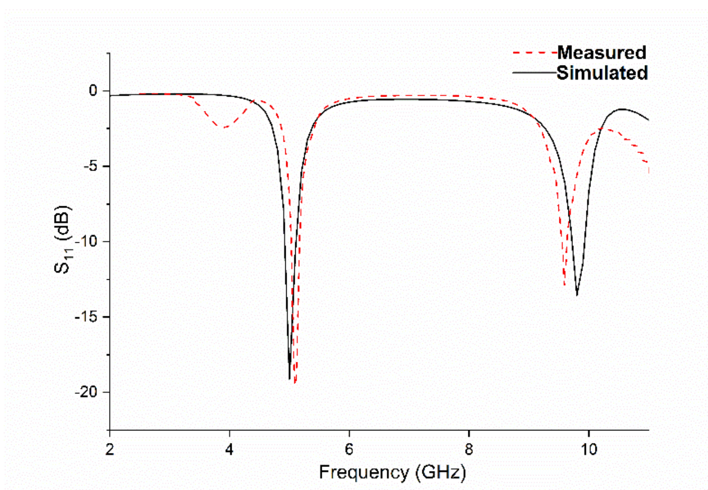


Figure 13. Measured and simulated of the reflection coefficient S_{11} of the proposed antenna.

validate the proposed design.

The radiation pattern measurements were conducted using Geozondas Ltd's "Antenna Measurement Systems" which allow for measuring different antenna characteristics such as antenna pattern over a wide frequency range of 2 to 26 GHz. The systems based on pulse (Time Domain, TD) measurements have advantages over traditional Frequency Domain (FD) techniques as they do not require an expensive anechoic chamber and can eliminate multiple parasitic reflections from walls, ceilings, and other objects with appropriate selection of delay and time window width for measurement.

The results of E-plane and H-plane measurements and simulations at both 5 GHz and 9.8 GHz, as shown in Figure 14, indicate that the proposed antenna has good radiation characteristics. The H-plane radiation pattern results are found to be symmetrical, suggesting a robust design for the antenna and potential applications in Industrial, Scientific, and Medical (ISM). The comparison of the simulation and measurement results indicates that the proposed structure is appropriate and accurately represents the behavior of the antenna. Overall, the invented antenna shows promising results, particularly in the H-plane at both frequencies.

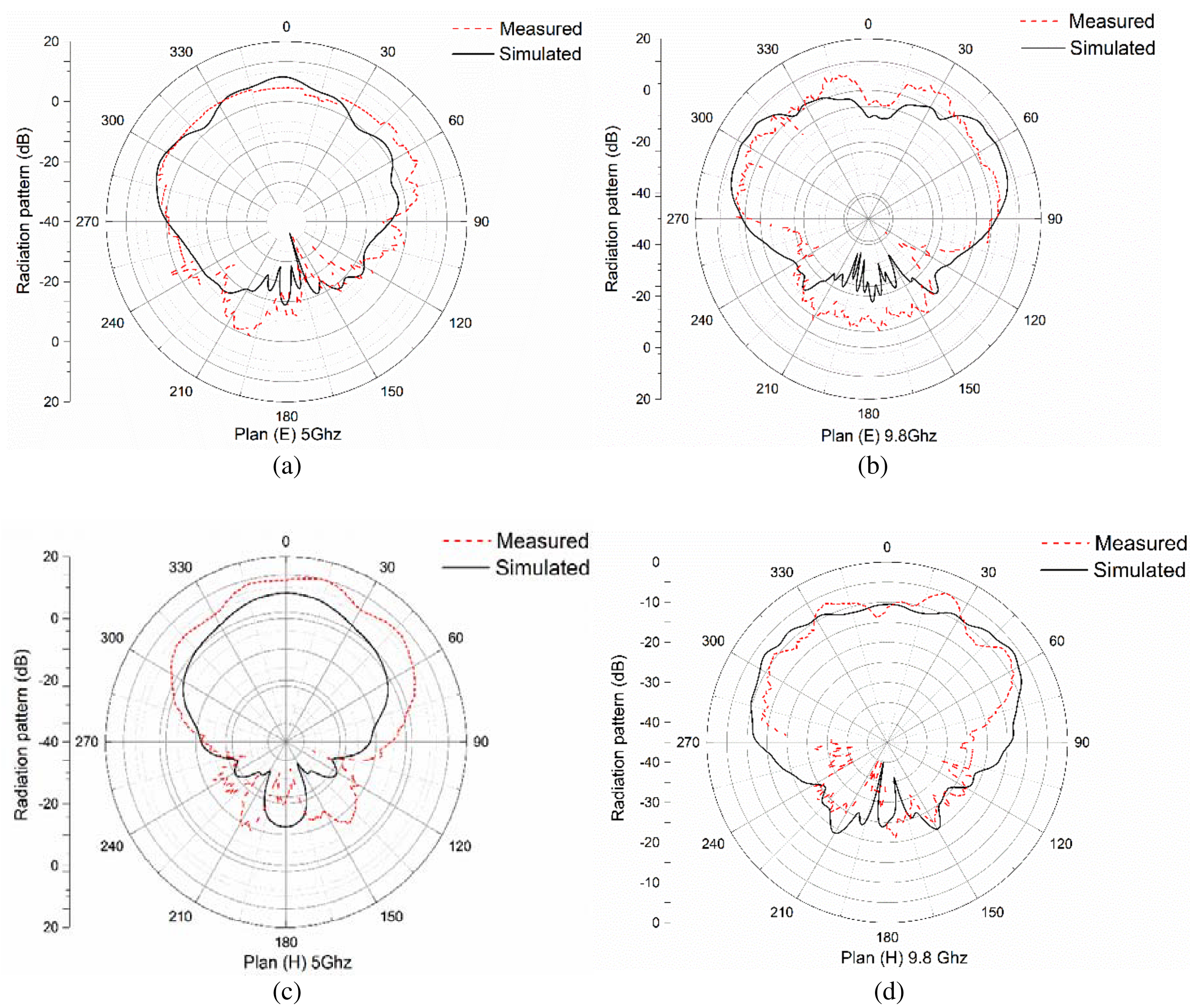


Figure 14. Radiation patterns for (a) Plan(E) 5 GHz, (b) Plan(E) 9.8 GHz, (c) Plan(H) 5 GHz, (d) Plan(H) 9.8 GHz.

A comparison of the proposed antenna design with previous published work is presented in Table 2. It is clearly observed that the proposed design stands out due to its sophisticated gain performance achieved through design optimizations.

Table 2. Comparaison with reported designs.

Reference	Topology	Permittivity (ε_r)	Freq (GHz)	Gain (dB)
[1]	FR4+EBG	4.4	5.2, 9	1.8, 2.3
[8]	FR4+EBG	4.4	5.8	5
[9]	RT duroid 5880+EBG	2.2	2.4, 5.2	7.91, 5.66
[10]	NA+EBG	-	3	5.1
This work	FR4+EBG	4.4	5, 9.8	8.17, 9.29

4. CONCLUSION

In this paper, the proposed dual-band dielectric EBG antenna, which operates in both WLAN and X-band satellite applications, has been shown to exhibit significant improvements in radiation performance at both 5 GHz and 9.8 GHz frequencies. The experimental results validate the effectiveness of the double EBG layer structure in enhancing the antenna's radiation characteristics. Based on these findings, it can be concluded that the proposed antenna design shows promise as a viable solution for dual-band applications, and its effectiveness and performance can be further optimized with additional research and development.

ACKNOWLEDGMENT

We express our sincere gratitude to Dr. Naima A. Touhami from the LASIT laboratory at the FS-Tetouan, Abdelmalek Essaadi University, for her valuable assistance in conducting the measurements and providing technical support during our experimental work for the coefficient reflection. We would also like to acknowledge the contribution of Dr. Ennasar, Mohammed Ali for his assistance in the measurement of the radiation pattern. Furthermore, we extend our appreciation to express our sincere appreciation to Dr. Mohssine El Ouahabi for his valuable contribution for fabricating the primary antenna using LPKF S63 machine.

REFERENCES

1. Beigi, P., M. Rezvani, Y. Zehforoosh, J. Nourinia, and B. Heydarpanah, "A tiny EBG-based structure multiband MIMO antenna with high isolation for LTE/WLAN and C/X bands applications," *International Journal of RF and Microwave Computer-Aided Engineering*, Vol. 30, No. 3, Mar. 2020, doi: 10.1002/mmce.22104.
2. Wu, W., B. Yuan, and A. Wu, "A quad-element UWB-MIMO antenna with band-notch and reduced mutual coupling based on EBG structures," *International Journal of Antennas and Propagation*, Vol. 2018, 1–10, 2018, doi: 10.1155/2018/8490740.
3. Balanis, C. A., *Antenna Theory: Analysis and Design*, 3rd Edition, John Wiley, Hoboken, NJ, 2005.
4. Pozar, D. M., *Microwave Engineering*, 2nd Edition, Vol. 736, Wiley, New York, 1998.
5. Wajid, A., A. Ahmad, S. Ullah, D. Choi, and F. U. Islam, "Performance analysis of wearable dual-band patch antenna based on EBG and SRR surfaces," *Sensors*, Vol. 22, No. 14, 5208, 2022, doi: 10.3390/s22145208.
6. Rmili, L., A. Asselman, A. Kaabal, S. Dellaoui, and M. El Halaoui, "High gain metallic electromagnetic band gap antenna for WLAN applications," *Mobile, Secure, and Programmable Networking*, É. Renault, S. Boumerdassi, C. Leghris, and S. Bouzefrane, 82–87, Springer International Publishing, Cham, 2019, doi: 10.1007/978-3-030-22885-9_8.

7. Bora, P., P. Pardhasaradhi, and B. Madhav, "Design and analysis of EBG antenna for Wi-Fi, LTE, and WLAN applications," *ACES*, Vol. 35, No. 9, 1030–1036, Nov. 2020, doi: 10.47037/2020.ACES.J.350908.
8. Hadj Sadok, M., Y. Lamhene, and S. Berkani, "High-gain low-profile EBG resonator antenna based on quasi-icosahedral shapes," *J. Electron. Mater.*, Vol. 52, No. 1, 140–152, Jan. 2023, doi: 10.1007/s11664-022-10046-6.
9. Wang, R., B.-Z. Wang, G.-F. Gao, X. Ding, and Z.-P. Wang, "Low-profile pattern-reconfigurable vertically polarized endfire antenna with magnetic-current radiators," *IEEE Antennas and Wireless Propagation Letters*, Vol. 17, No. 5, 829–832, 2018, doi: 10.1109/LAWP.2018.2817682.
10. Karthikeya, G. S., S. Kaundinya, and S. A. Hariprasad, "Dual band hexagonal microstrip antenna loaded with hexagonal and cylindrical EBG," *2014 IEEE Fifth International Conference on Communications and Electronics (ICCE)*, 385–390, IEEE, Danang, Vietnam, 2014, doi: 10.1109/CCE.2014.6916734.
11. Zoubiri, B., A. Mayouf, F. Mayouf, S. Abdelkebir, and T. Devers, "Enhancement of front-to-back ratio and gain of rectangular microstrip antenna using novel elliptical EBG structure," *Microsystem Technologies*, Vol. 24, No. 8, 3241–3244, 2018, doi: 10.1007/s00542-018-3855-9.
12. Guo, H. and W. Geyi, "Design of bidirectional antenna array with adjustable endfire gains," *IEEE Antennas and Wireless Propagation Letters*, Vol. 18, No. 8, 1656–1660, 2019, doi: 10.1109/LAWP.2019.2926525.
13. Hassan, M. U., F. Arshad, S. I. Naqvi, Y. Amin, and H. Tenhunen, "A compact flexible and frequency reconfigurable antenna for quintuple applications," *Radioengineering*, Vol. 26, No. 3, 655–661, Sept. 2017, doi: 10.13164/re.2017.0655.
14. Boudaghi, H., M. Azarmanesh, and M. Mehranpour, "A frequency-reconfigurable monopole antenna using switchable slotted ground structure," *IEEE Antennas and Wireless Propagation Letters*, Vol. 11, 655–658, 2012, doi: 10.1109/LAWP.2012.2204030.
15. Benikhlef, M. F. and M. N. Boukli-Hacen, "Effects of two dimensional electromagnetic bandgap (EBG) structures on the performance of microstrip patch antenna arrays," 2016, https://www.semanticscholar.org/paper/Effects-of-Two-Dimensional-Electromagnetic-Bandgap-Benikhlef-Boukli-Hacen/eefc878e62763dd0d42c98f813ac65ec97d3e1b4 (consulté le 24 Mars 2023).
16. Choubani, M., F. Choubani, A. Gharsallah, J. David, and N. E. Mastorakis, "Analysis and design of electromagnetic band gap structures with stratified and inhomogeneous media," *Optics Communications*, Vol. 283, No. 22, 4499–4504, Nov. 2010, doi: 10.1016/j.optcom.2010.04.078.
17. Samsuzzaman, M., M. T. Islam, N. Misran, and M. A. M. Ali, "Dual band X shape microstrip patch antenna for satellite applications," *Procedia Technology*, Vol. 11, 1223–1228, 2013, doi: 10.1016/j.protcy.2013.12.317.
18. Raimondo, L., F. De Paulis, and A. Orlandi, "A simple and efficient design procedure for planar electromagnetic bandgap structures on printed circuit boards," *IEEE Transactions on Electromagnetic Compatibility*, Vol. 53, No. 2, 482–490, 2011, doi: 10.1109/TEMC.2010.2051549.
19. Viswanadha, K. and N. S. Raghava, "Design and analysis of a compact dual-band serpentine-shaped patch antenna with folded stub lines for C- and X-band applications," *Journal of Communications Technology and Electronics*, Vol. 65, No. 10, 1147–1160, Oct. 2020, doi: 10.1134/S106422692010006X.
20. Li, R., C. Wu, X. Sun, Y. Zhao, and W. Luo, "An EBG-based triple-band wearable antenna for WBAN applications," *Micromachines*, Vol. 13, No. 11, 1938, Nov. 2022, doi: 10.3390/mi13111938.

Erratum to "A Novel EBG Dual-Band Antenna Structure for X-Band and WLAN Applications"

by Loubna Rmili*, Bousselham Samoudi, Adel Asselman, and Sanae Dellaoui, in *Progress in Electromagnetic Research C*, Vol. 135, 13–22, 2023

Loubna Rmili*, Bousselham Samoudi, Adel Asselman, and Sanae Dellaoui

Mistake 1: In Equation (1) in page 2, the equation was incorrectly stated as :

$$L_{\text{sub}} = \frac{10^{\frac{D_{db}}{10}} \cdot \lambda_0^2}{0.8\pi^2}$$

Correction 1: The correct version of the equation is:

$$L_{\text{sub}} = \sqrt{\frac{10^{\frac{D_{db}}{10}} \cdot \lambda_0^2}{0.8\pi^2}}$$

Explanation 1: This correction does not affect the overall conclusions of the paper, as the corrected equation was used in all calculations and simulations (It was just a typo).

Mistake 2: The reference cited in section [Antenna Structure without EBG] as ref. [11] was incorrect:

Zoubiri, B., A. Mayouf, F. Mayouf, S. Abdelkebir, and T. Devers, "Enhancement of front-to-back ratio and gain of rectangular microstrip antenna using novel elliptical EBG structure," *Microsystem Technologies*, Vol. 24, No. 8, 3241–3244, 2018, doi: 10.1007/s00542-018-3855-9.

Correction 2: The correct reference should be:

Leger, L., C. Serier, R. Chantalat, M. Thevenot, T. Monedire, and B. Jecko, "1d dielectric electromagnetic band gap (EBG) resonator antenna design," *Annals of telecommunications*, Vol. 59, 242–260, Springer, 2004.

Explanation 2: This correction is necessary to ensure readers to have access to the correct sources for further reading.

Apology and Acknowledgments: We apologize for any inconvenience that these errors may have caused to the readers.

Received 20 May 2024, Added 21 May 2024

* Corresponding author: Loubna Rmili (loubna.rmili@etu.uae.ac.ma).
The authors are with the Optics, Material and Systems Team, Faculty of Sciences, Abdelmalek Essaadi University, P.O. Box: 2121, Tetouan, Morocco.