Progress In Electromagnetics Research Letters, Vol. 125, 51–57, 2025

PIER Letters

(Received 17 January 2025, Accepted 26 February 2025, Scheduled 12 March 2025)

EBG-Based Low Profile Corrugated Antenna for 5G Applications in Sub-6 GHz Spectrum

Hema Raut[1,2], Saffrine Kingsly[2,*], Sangeetha Subbaraj[3], and Rajeshwari Malekar[2,4]

[1]*Electronics and Computer Science Department, South Indian Education Society-Graduate School of Technology, Nerul, India*
[2]*Electronics and Telecommunication Department, Symbiosis Institute of Technology, Pune, India*
[3]*Department of Electronics and Communication Engineering, College of Engineering, Guindy, Anna University, Chennai, India*
[4]*Electronics and Telecommunication Department, Marathwada Mitra Mandal's College of Engineering, Pune, Maharashtra, India*

ABSTRACT: The paper describes a two-layer low-profile antenna design suitable for sub-6 GHz communications that operates at 5.8 GHz. The proposed antenna is integrated with a periodic plus-shaped EBG structure to obtain gain and bandwidth enhancement. The realized gains of the prototype with and without periodic structure are 3.48 dBi and 2.4 dBi, respectively. Additionally, it is observed that the measured bandwidth of the antenna structure at 5.75 GHz with periodic structure is 230 MHz, while without periodic structure it is 150 MHz, which accounts for 35% bandwidth enhancement. The simulated and measured results validate that the proposed compact antenna prototype is a suitable candidate for sub-6 GHz application in the 5G spectrum.

1. INTRODUCTION

The need for high gain, low cost, compact, and high data speed antenna designs has grown over time. Many applications, such as AR/VR gaming, self-driving systems with networked vehicles, and smart devices with HD streaming capabilities, require large bandwidth. 5G technology advancements can quench the demand for fast data speeds, low latency, more bandwidth, and extensive coverage [1, 2]. Also, the design advancements for 5G antennas have allowed researchers to work on these attributes. Additionally, a large spectrum, spanning from 24,250 MHz to 71,000 MHz, is supported by 5G. The 5G spectrum comprises FR1 (frequency range 1) band, also known as sub-6 GHz range, and FR2 (frequency range 2) band, also known as millimeter wave range [3, 4].

Better reliability and a wider coverage area in the sub-6 GHz spectrum have led to a revolution in various fields, including the Internet of Everything (IoE) and cloud computing. Also, the communication systems designed in this band exhibit minimum attenuation, low fading and attenuation [5]. This has attracted researchers to explore various antenna design techniques, including single-element and multi-element antenna structures. Antenna design and its parameters like gain, return loss, bandwidth, directivity, and radiation efficiency play a significant role in any communication system [6]. Multi-element antenna designs are popular because single-element antennas have limited gain and bandwidth. Large bandwidth and high gain can be obtained with multi-element antenna designs. However, the feeding network's architecture could be complex in nature. The antenna size may therefore grow [7, 8].

The available literature also focuses on electromagnetic periodic structure-based antenna designs that can potentially enhance antenna parameters. Engineered materials with altered electromagnetic characteristics, like permeability and permittivity, are known as electromagnetic periodic structures. Materials that possess permittivity (ϵ) and permeability (μ) values below zero are referred to as metamaterials. Repeating metallic structures, often known as unit cells, allow these properties to be altered to suit specific needs. The unit cells are arranged periodically, which modifies the material's characteristics by affecting its capacitive and inductive behaviour. It is required that the unit cell dimension be less than one-tenth of lambda [9, 10]. Metamaterials include a wide range of structures like electromagnetic band gap (EBG) structure suitable for minimizing back radiation can provide gain and bandwidth enhancement [11, 12]; artificial magnetic conductors (AMCs) suppress surface wave and undesired radiations, much similar to EBG structures [13, 14]; frequency selective surface (FSS) resembles filter characteristics and can provide gain improvement [15, 16]; partially reflective surface (PRS) supports wideband and provides directive radiation pattern [17, 18]; high impedance surface (HIS) aids in minimizing undesired side lobes and beam distortion [19, 20]. These papers describe new results in the field of microwave and wireless technologies.

Further, EBG periodic structures are versatile due to their ability to behave as AMC, HIS, or FSS layer thereby providing low profile structures, enhancement in terms of surface wave suppression, radiation characteristics, gain and bandwidth [21]. The proposed EBG based 5G antenna structure provides enhanced performance and can support wireless applications in sub-6 GHz spectrum. The antenna designs with and without periodic structure exhibit the same dimensions in terms of length and width with minimal difference in the height.

* Corresponding author: Saffrine Kingsly (kingsly.saffrine@gmail.com).

doi:10.2528/PIERL25011701

Published by THE ELECTROMAGNETIC ACADEMY

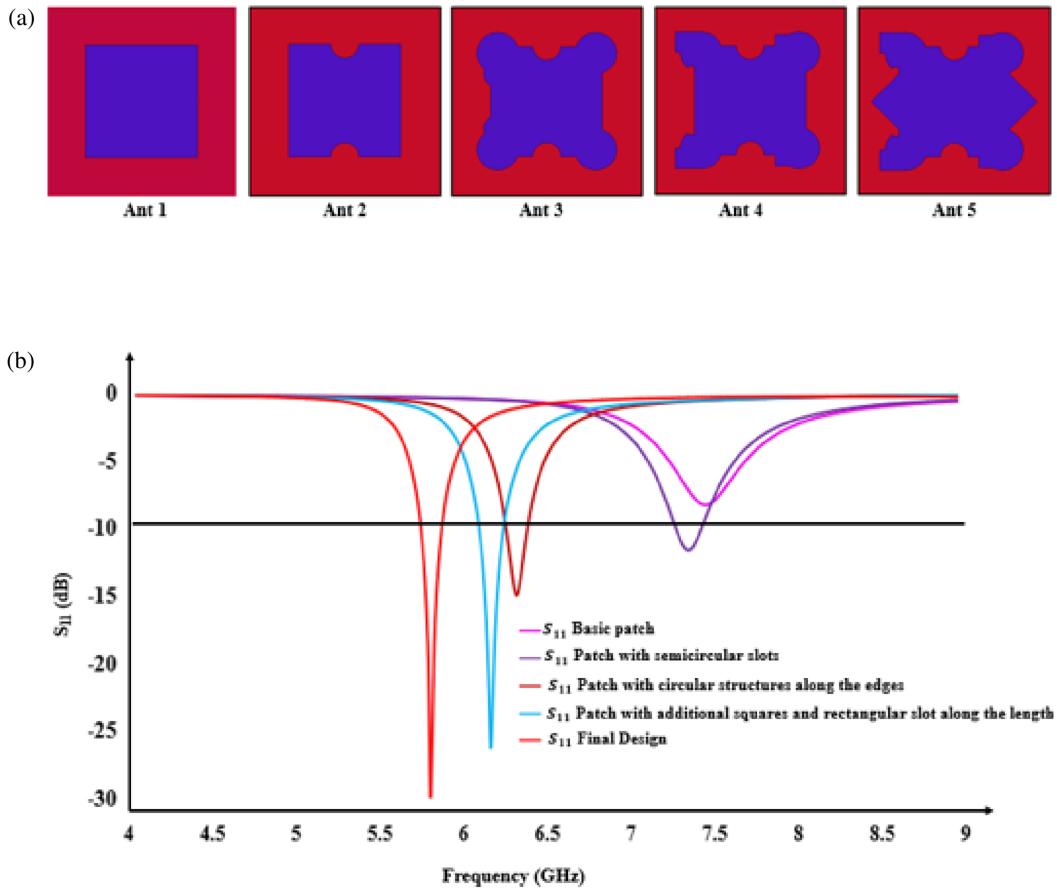

FIGURE 1. Proposed antenna. (a) Front view. (b) Side view.

2. ANTENNA DESIGN

The paper proposes a 2-layered EBG-backed 5G antenna design with 3.48 dBi gain and 230 MHz bandwidth to support sub-6 GHz applications.

2.1. Single Element 5G Antenna

The antenna evolution and the corresponding S-parameter plot for each stage are highlighted in Fig. 1(a) and Fig. 1(b), respectively. Ant 1 represents a basic patch operating at 7.5 GHz with poor impedance matching. Ant 2 includes semicircular slots on either side of the design, which increases the electrical length and provides a relatively better impedance matching at 7.36 GHz. The objective of the proposed work is to resonate the antenna at 5.8 GHz, so to increase the electrical length further, and circular structures are added along the edges, as shown in Ant 3. As a result, now the patch resonates at 6.32 GHz. To resonate the antenna at the desired frequency, the overall length of the patch should be increased. To improve the impedance matching, a rectangular slot is added, as shown in Ant 4. It also increases the electrical length of the antenna; therefore, Ant 4 resonates at 6.16 GHz with low losses.

The final stage of antenna design exhibits the inclusion of squares rotated by 45° along the feed line. The rotated square structures significantly increase the resultant surface area of Ant 5, causing the antenna to resonate at 5.8 GHz with a relative bandwidth of 150 MHz. The proposed antenna, as depicted in Fig. 2, is designed on FR4 (substrate 1) with a height (h) of 1.5 mm, relative permittivity (ϵ_r) of 4.4, and dielectric loss of 0.02. The antenna measures $14 \times 14 \times 1.5\,\text{mm}^3$ with a gain of 2.4 dBi and resonates at 5.8 GHz with an operating band of 150 MHz (5.72 GHz to 5.87 GHz).

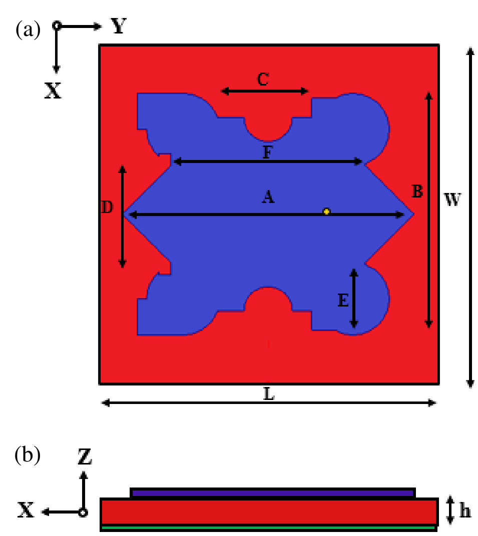

FIGURE 2. Proposed antenna. (a) Front view. (b) Side view.

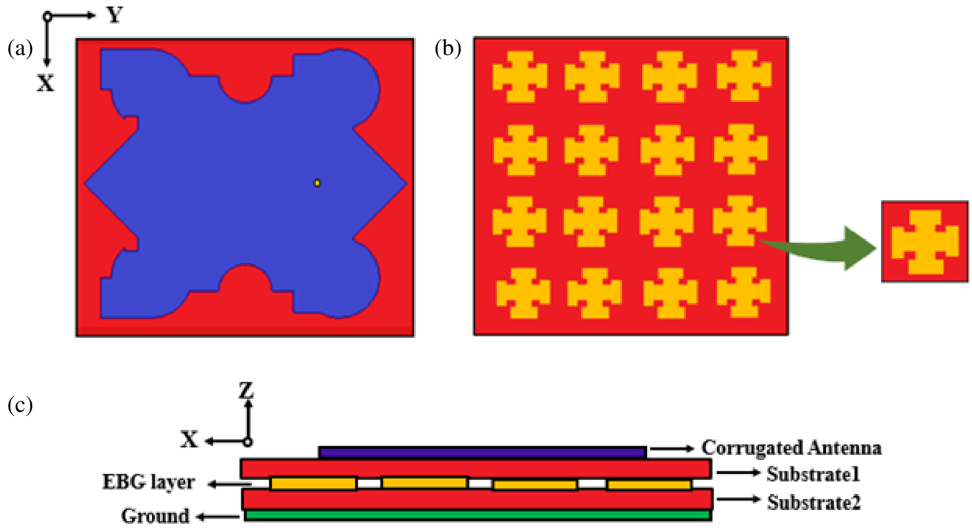

FIGURE 3. Antenna with periodic structure (a) Proposed antenna (b) Periodic structure top view (c) Side view.

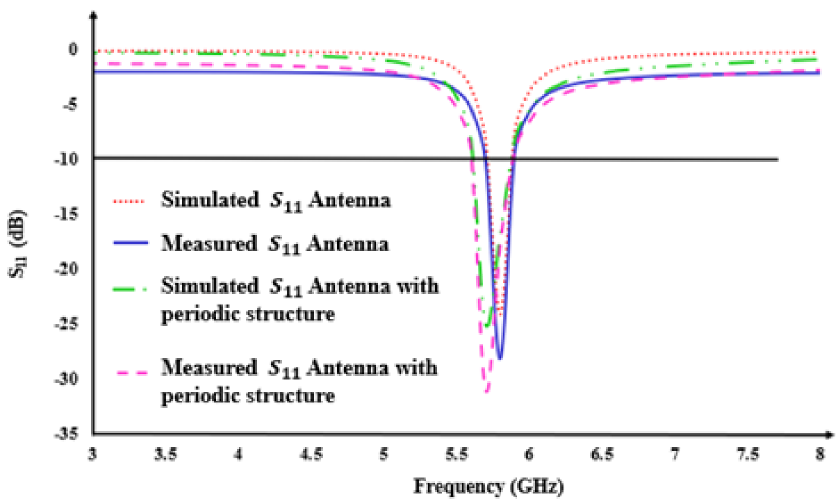

FIGURE 4. Measured and simulated S-parameter plots of the proposed antenna.

Researchers widely use FR4 substrate for antenna designs. FR4 substrate exhibits strong mechanical characteristics and is cost efficient. However, the relative dielectric constant is high, and as a result, the electromagnetic waves travel at low speed limiting the gain and bandwidth [22]. In addition, FR4 based antenna design can cover ISM and X-band applications [23].

The corrugated prototype increases the electrical length and the path traversed by current, thereby resonating the patch at a relatively lower frequency. Table 1 shows antenna dimensions.

TABLE 1. Antenna dimensions.

Parameters	Dimensions (mm)	Parameters	Dimensions (mm)
L	14	W	14
A	12	B	10
C	3.8	D	4
E	3	F	8

2.2. Antenna Design with Periodic Structure

Fig. 3 depicts the antenna design with a periodic structure. The EBG layer positioned below the antenna reduces surface current and suppresses back radiations which in turn improves radiation characteristics and efficiency. Fig. 4 depicts return loss of -31.3 dB with a measured bandwidth of 230 MHz (5.64 GHz–5.87 GHz) at 5.75 GHz.

3. RESULTS AND DISCUSSION

The antenna structures are proposed and simulated in commercially available Ansys HFSS software, and the performance parameters such as bandwidth, gain, radiation pattern, and current distribution are observed.

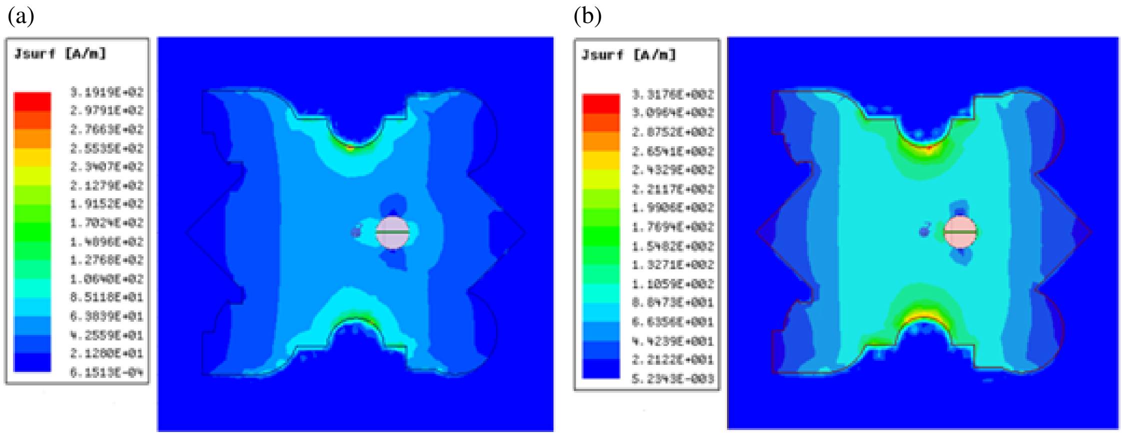

FIGURE 5. Current distribution of proposed antenna. (a) Aingle element antenna. (b) Antenna with EBG layer.

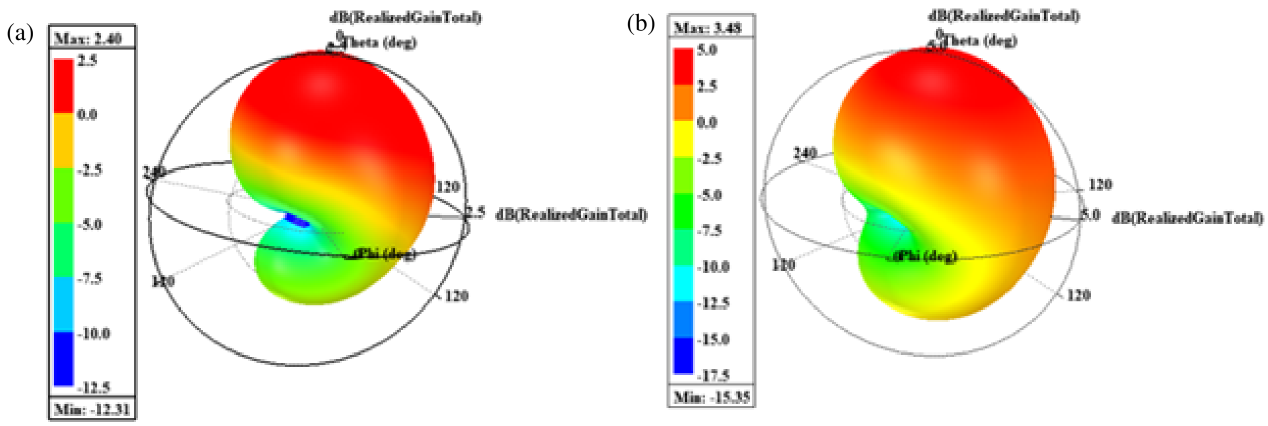

FIGURE 6. 3D-gain plot of proposed antenna. (a) Single corrugated antenna. (b) Corrugated antenna with EBG layer.

3.1. Single Element 5G Antenna

The probe-fed antenna design without EBG is simulated and matched with the measured results. Fig. 4 represents return loss with a minimum reflection coefficient of -27.8 dB. The measured impedance bandwidth at 5.8 GHz is 150 MHz (5.72 GHz–5.87 GHz). The maximum realized gain obtained is 2.4 dBi and is constant over the operating band.

3.2. Corrugated Antenna Design With Periodic Structure

The corrugated antenna structure is backed by an EBG structure that consists of an array of 6×6 square unit cells. Further, the performance of the antenna with periodic structure in terms of gain and return loss is enhanced. As depicted in Fig. 4, the peak simulated and measured reflection coefficients at 5.75 GHz are -26.2 dB and -31.3 dB, respectively. The proposed antenna provides a relatively wide measured return loss bandwidth of 230 MHz from 5.64 GHz to 5.87 GHz whereas the simulated bandwidth observed is 220 MHz (5.61 GHz–5.83 GHz).

Furthermore, Fig. 5 depicts the current distribution pattern for the designed antenna prototype, highlighting the changes in the current density over the antenna surface. It shows that the current has a higher value near the periphery, which enhances the radiation pattern and thus accounts for more bandwidth. Fig. 6 highlights 3D gain plot with a realized gain of 3.48 dBi for antenna with periodic structure and 2.4 dBi for simple antenna structure.

Figure 7 presents 2D gain plot of the proposed antenna highlighting stable gain over the operating band. The gain can be further enhanced by introducing an air gap between the two substrates. The 2D radiation pattern of the proposed antenna at 5.75 GHz is shown in Fig. 8. The variation of electric field with respect to phi represents co-polarization ($\Theta = 0°$) and cross-polarization ($\Theta = 90°$). Similarly, the co-polarization ($\Phi = 0°$) and cross polarization ($\Phi = 90°$) of magnetic field are observed. The measured and simulated results are consistent with slight differences due to the limitations of the measuring equipment.

Figure 9 depicts the fabricated antenna prototypes. Fig. 9(a) and Fig. 9(b) present the top view of the antenna and the periodic structure, and the side view of the EBG backed antenna probe fed antenna is highlighted in Fig. 9(c).

A compact wideband corrugated radiating structure has been presented. The EBG structure, made up of 4×4 unit cells, improves gain and return loss bandwidth. Table 2 summarizes the performance of the designed antenna and its comparison in

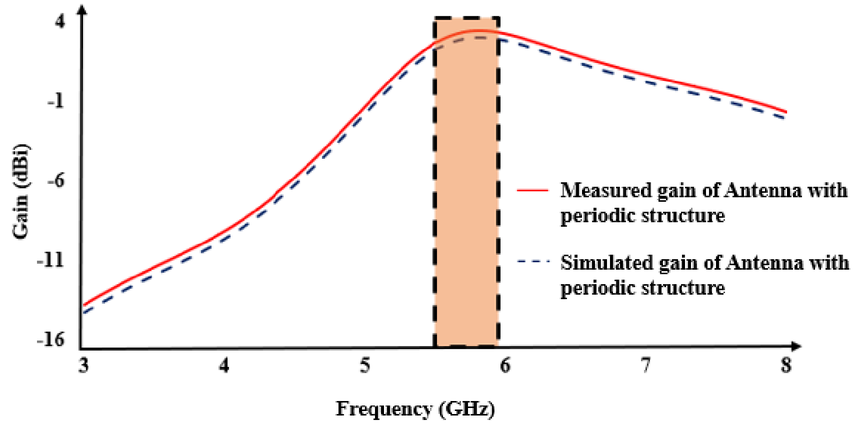

FIGURE 7. 2D Gain plot of the proposed EBG backed antenna prototype.

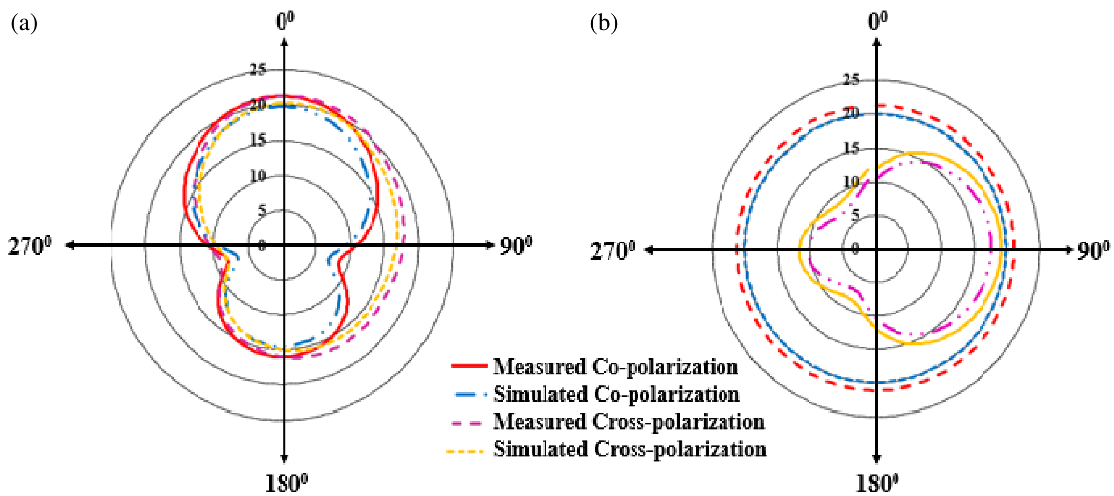

FIGURE 8. Radiation pattern of the proposed antenna. (a) H-Plane pattern. (b) E-plane pattern.

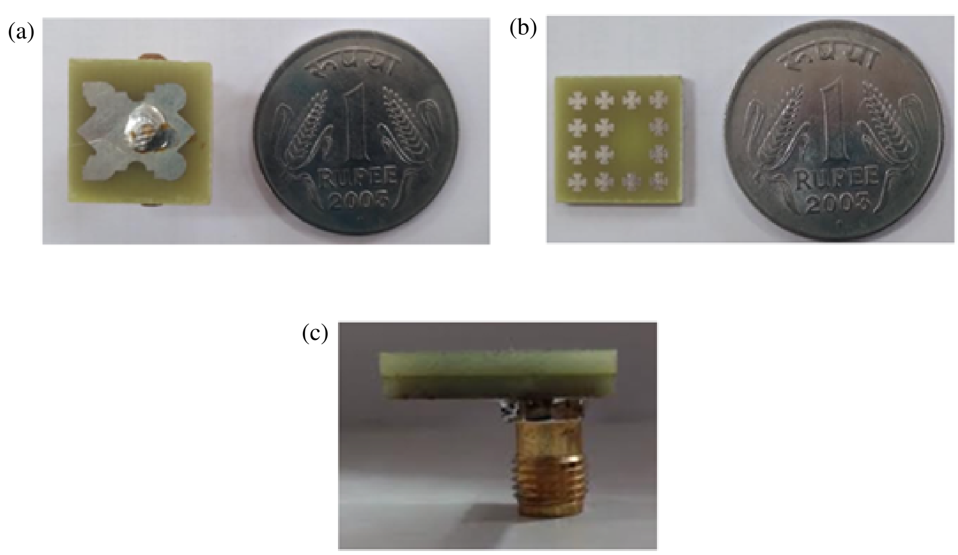

FIGURE 9. Fabricated antenna prototype: (a) Top view, (b) Periodic structure, (c) Side view.

TABLE 2. Performance comparison with the current state of art.

Ref.	Size (λ_0^3) mm	Frequency (GHz)	Bandwidth (MHz)	Substrate	Comment
[10]	$0.55 \times 0.467 \times 0.019$	3.5	430	FR4	Metamaterial based design with good bandwidth but less gain.
[12]	$0.45 \times 0.44 \times 0.036$	3.6	80	FR4	large in size narrow bandwidth.
[14]	$0.79 \times 0.79 \times 0.029$	2.51, 3.36, 5.72	240, 110, 230	FR4	Large prototype , relatively less bandwidth.
[18]	$0.23 \times 0.76 \times 0.013$	2.4	70	FR4	Compact prototype, narrow bandwidth.
[19]	$0.24 \times 0.3 \times 0.03$	3.5	80	$BiNbO_4(V_2O_5)$	substrate with high ϵ_r, provides less bandwidth.
This work	$0.26 \times 0.26 \times 0.0567$	5.75	230	FR4	Compact design with relatively wide bandwidth.

λ_0 in mm

reference to dimension, resonating frequency, effective bandwidth, and the substrate used. The proposed design exhibits compact size with respect to [10, 12, 14] and a relatively wide bandwidth as compared to [12, 18, 19]. In addition, the realized antenna gain with EBG structure is 3.48 dBi at 5.75 GHz.

Salient features of the prototype designed

1. The proposed prototype emphasizes the performance enhancement of a 5G antenna design using a plus shaped periodic structure. Each unit cell of dimension $0.029\lambda_0 \times 0.029\lambda_0$ with a spacing of $0.019\lambda_0$ limits the back lobe and promotes directivity compared to the prototype without EBG depicted in [10] and [18].
2. The prototype is fabricated on an FR4 substrate, which is cost-efficient as compared to [19]. Also, the design is free of complex structures like vias or shorting pins, thereby making it less bulky.
3. The overall size of the EBG layer is kept the same as that of the antenna, resulting in a compact prototype with bandwidth enhancement of 35% as compared to [12, 14, 18, 19].
4. Compared to [12, 18, 19], the bandwidths of the designed prototype with and without periodic structure are wider, 230 MHz and 150 MHz, respectively.

4. CONCLUSION

The proposed study provides a corrugated antenna construction for 5G applications supported by an EBG framework. The designed and fabricated antenna prototype supports sub-6 GHz band and can provide extensive coverage. With an improved bandwidth of 230 MHz, the designed antenna structure yields a 3.48 dBi gain. Furthermore, the usage of periodic structure suppresses unwanted radiations, resulting in a directed radiation pattern. Antenna parameters validate that the proposed compact 5G antenna can support 5G communication in sub-6 GHz spectrum.

REFERENCES

[1] Hong, W., Z. H. Jiang, C. Yu, J. Zhou, P. Chen, Z. Yu, H. Zhang, B. Yang, X. Pang, M. Jiang, *et al.*, "Multibeam antenna technologies for 5G wireless communications," *IEEE Transactions on Antennas and Propagation*, Vol. 65, No. 12, 6231–6249, 2017.

[2] Huang, H.-C., "Overview of antenna designs and considerations in 5G cellular phones," in *2018 International Workshop on Antenna Technology (iWAT)*, 1–4, Nanjing, China, Mar. 2018.

[3] ITU-R, "Guidelines for evaluation of radio interface technologies for IMT-2020," Report ITU-R M.2412-0, 1–144, 2017.

[4] ITU-R, "Technical feasibility of IMT in bands above 6 GHz," Report ITU-R M.2376-0, 1–134, 2015.

[5] Kaushal, D. and T. Shanmuganantham, "Comparative analysis of microstrip moody patch antenna for space applications," in *2016 International Conference on ElectroMagnetic Interference & Compatibility (INCEMIC)*, 1–4, Bengaluru, India, 2016.

[6] Kumar, S., A. S. Dixit, R. R. Malekar, H. D. Raut, and L. K. Shevada, "Fifth generation antennas: A comprehensive review of design and performance enhancement techniques," *IEEE Access*, Vol. 8, 163 568–163 593, 2020.

[7] Zhu, Q., K. B. Ng, C. H. Chan, and K.-M. Luk, "Substrate-integrated-waveguide-fed array antenna covering 57–71 GHz band for 5G applications," *IEEE Transactions on Antennas and Propagation*, Vol. 65, No. 12, 6298–6306, 2017.

[8] Dzagbletey, P. A. and Y.-B. Jung, "Stacked microstrip linear array for millimeter-wave 5G baseband communication," *IEEE Antennas and Wireless Propagation Letters*, Vol. 17, No. 5, 780–783, 2018.

[9] Schurig, D., J. J. Mock, B. J. Justice, S. A. Cummer, J. B. Pendry, A. F. Starr, and D. R. Smith, "Metamaterial electromagnetic cloak at microwave frequencies," *Science*, Vol. 314, No. 5801, 977–980, 2006.

[10] Wang, C., X.-S. Yang, and B.-Z. Wang, "A metamaterial-based compact broadband planar monopole MIMO antenna with high isolation," *Microwave and Optical Technology Letters*, Vol. 62, No. 9, 2965–2970, 2020.

[11] Tan, X., W. Wang, Y. Wu, Y. Liu, and A. A. Kishk, "Enhancing isolation in dual-band meander-line multiple antenna by employing split EBG structure," *IEEE Transactions on Antennas and Propagation*, Vol. 67, No. 4, 2769–2774, 2019.

[12] Raut, H., S. Kingsly, S. Subbaraj, and R. Malekar, "EBG-based slotted T-shaped antenna for sub-6 GHz 5G application," *International Journal of Electronics Letters*, Vol. 12, No. 4, 375–387, 2024.

[13] Liu, Q., H. Liu, W. He, and S. He, "A low-profile dual-band dual-polarized antenna with an AMC reflector for 5G communications," *IEEE Access*, Vol. 8, 24 072–24 080, 2020.

[14] Hu, T., Z. Pan, M. Saitou, J. Liu, and S. Shimamoto, "A triple-band antenna loaded with reflector surface for WLAN and 5G applications," *Journal of Communications*, Vol. 15, No. 10, 729–734, 2020.

[15] Azemi, S. N., F. H. W. Mustaffa, M. F. Jamlos, A. A. Al-Hadi, and P. J. Soh, "Frequency selective surface for structural health monitoring," in *IOP Conference Series: Materials Science and Engineering*, Vol. 318, No. 1, 012033, 2018.

[16] Nakmouche, M. F., A. Allam, D. E. Fawzy, and D.-B. Lin, "Development of a high gain FSS reflector backed monopole antenna using machine learning for 5G applications," *Progress In Electromagnetics Research M*, Vol. 105, 183–194, 2021.

[17] Goudarzi, A., M. Movahhedi, M. M. Honari, and R. Mirzavand, "Design of a wideband single-layer partially reflective surface for a circularly-polarized resonant cavity antenna," *AEU — International Journal of Electronics and Communications*, Vol. 129, 153535, 2021.

[18] Sharma, K. and G. P. Pandey, "Two port compact MIMO antenna for ISM band applications," *Progress In Electromagnetics Research C*, Vol. 100, 173–185, 2020.

[19] Miranda, I. R. S., F. M. de Sousa, F. B. de Sousa, J. E. de Oliveira, and M. B. C. Costa, "Microstrip patch antenna with $BiNbO_4(V_2O_5)$ substrate and copper periodic structures," *Materials Research*, Vol. 24, No. 5, e20200487, 2021.

[20] Nelaturi, S. and N. V. S. N. Sarma, "Compact wideband microstrip patch antenna based on high impedance surface," *Engineering, Technology & Applied Science Research*, Vol. 8, No. 4, 3149–3152, 2018.

[21] Krishnananda and T. S. Rukmini, "EBG antennas: Their design and performance analysis for wireless applications," *International Journal of Computer Applications*, Vol. 48, No. 23, 20–27, 2012.

[22] Srinivasu, G., T. Gayatri, D. M. K. Chaitanya, and V. K. Sharma, "Influence of FR4 material substrate on diamond slotted ultra wideband antenna in 1.71 GHz to 12 GHz," *Materials Today: Proceedings*, Vol. 45, 5642–5648, 2021.

[23] Sandeep, D. R. and G. V. Sivanvitha, "Design of low-cost compact FR-4 microstrip patch antenna for 5G, ISM, and X-band applications," in *2024 IEEE Wireless Antenna and Microwave Symposium (WAMS)*, 1–5, Visakhapatnam, India, Feb. 2024.