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Milimetre Dalga Uygulamaları için Çok Bantlı Mikroşerit Yama Anten Tasarımı ve Analizi

Design and Analysis of a Multiband Microstrip Patch Antenna for Millimeter Wave Applications

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Öz

Bu çalışma, milimetre dalga (mmWave) frekans bandında çalışan beşinci nesil (5G) kablosuz iletişim sistemleri için tasarlanmış, kompakt ve çok bantlı, kaplumbağa şekilli özgün geometride bir mikroşerit yama antenin (MYA) tasarımını ve nümerik analizini sunmaktadır. Önerilen anten, merkezi eliptik bir yama, yamanın her iki yanında simetrik olarak konumlandırılmış iki döngü yapısı ve performansı artırmak amacıyla entegre edilmiş yarım dairesel yarıklardan oluşan özgün bir konfigürasyona sahiptir. Anten, dielektrik sabiti (ε_r) 2.2 ve kayıp tanjantı (tanδ) 0.0009 olan Taconic TLY-5 alt tabaka üzerinde, 32 × 14 × 0.381 mm³ boyutlarında dizayn edilmiştir. Düşük kayıp özelliği ve üretim süreçleriyle uyumluluğu nedeniyle mikroşerit hat besleme yöntemi kullanılmıştır. Elektromanyetik performans değerlendirmeleri, Computer Simulation Technology (CST) yazılımı ile gerçekleştirilmiştir. Simülasyon sonuçları, antenin 26.29 GHz, 28.44 GHz, 34.25 GHz, 36.75 GHz, 39.17 GHz ve 42.40 GHz merkez frekanslarında verimli çalıştığını göstermektedir. Bu frekanslardaki kazanç değerleri sırasıyla 6.69 dBi, 9.82 dBi, 8.58 dBi, 10.44 dBi, 10.37 dBi ve 7.50 dBi olarak ölçülmüştür. Ayrıca, anten geniş çalışma bant genişliği, düşük S11 değerleri, uygun Gerilim Durum Dalga Oranı (VSWR) değerleri ve kararlı ışıma desenleri sergileyerek, çok bantlı 5G mm dalga uygulamaları için yüksek performanslı çözüm sunmaktadır.

Anahtar Kelimeler: 5G kablosuz iletişim, milimetre dalga, mikroşerit yama anten, çok bantlı, kazanç

Abstract

This study presents the design and numerical analysis of a compact, multiband, turtle-shaped microstrip patch antenna (MPA) with a novel geometry, developed for fifth-generation (5G) wireless communication systems operating in the millimeter wave (mmWave) frequency band. The proposed antenna features a original configuration composed of a central elliptical patch, two symmetrically positioned loop structures on either side of the patch, and integrated semi-circular slots designed to enhance performance. The antenna is designed on a Taconic TLY-5 substrate with a dielectric constant (ε_r) of 2.2 and a loss tangent (tanδ) of 0.0009, with overall dimensions of 32 × 14 × 0.381 mm³. Due to its low-loss characteristics and compatibility with fabrication processes, a microstrip line feeding technique has been employed. Electromagnetic performance evaluations were conducted using Computer Simulation Technology (CST) software. Simulation results indicate that the antenna operates efficiently at center frequencies of 26.29 GHz, 28.44 GHz, 34.25 GHz, 36.75 GHz, 39.17 GHz, and 42.40 GHz. The corresponding gain values at these frequencies are measured as 6.69 dBi, 9.82 dBi, 8.58 dBi, 10.44 dBi, 10.37 dBi, and 7.50 dBi, respectively. Furthermore, the antenna exhibits a wide operational bandwidth, low S11 values, favorable Voltage Standing Wave Ratio (VSWR) values, and stable radiation patterns, offering a high-performance solution for multiband 5G mmWave applications.

Keywords: 5G wireless communication, millimeter wave, microstrip patch antenna, multiband, gain

1. Introduction

Fifth-generation (5G) wireless communication technologies offer effective solutions to the rapidly increasing global data traffic, intensive user demands, and high-speed connectivity requirements. Therefore, 5G technologies have become one of the fundamental building blocks of modern communication systems [1]. The utilization of millimeter wave (mmWave) frequency bands in 5G technologies has highlighted factors such as compactness, lightweight, planar structure, multi-band operation capability, and cost-effective manufacturing in antenna design. [2]. In this context, microstrip patch antennas (MPAs) have been adopted as one of the most suitable solutions in terms of both performance and integration. However, MPAs exhibit performance limitations such as low gain, narrow bandwidth and high-quality factors. At mmWave frequencies, attenuation of electromagnetic waves in the atmosphere increases transmission losses, adversely affecting communication efficiency. Accordingly, there is a growing demand for high-gain antenna designs to ensure efficient operation of systems operating in the mmWave band [3]. In addition to future 5G networks, rapidly evolving technological trends in wireless communication systems necessitate devices to support multiple frequency bands. [4]. Under these conditions, the use of multi-band antennas is becoming increasingly prevalent to enable networks to simultaneously access different frequency bands. This requirement underscores the need for more efficient antenna designs capable of supporting multiple applications through a single antenna, particularly in mobile and satellite communication systems. Recently, research focusing on patch antennas exhibiting multi-band performance at mmWave frequencies has intensified, and the literature in this field is becoming increasingly comprehensive [4-7].

In the study conducted by Sadek et al. [5], a microstrip line-fed patch antenna with dimensions of 16.5 × 16.5 × 0.81 mm³ was designed for 5G applications. The antenna features a triple L-arms (TLA) patch structure that provides multiband operation, and its bandwidth was aimed to be enhanced by incorporating a diamond-shaped ground slot. The designed antenna operates at four different frequencies: 10 GHz, 13 GHz, 17 GHz, and 26 GHz, achieving gain values of 4.95 dB, 5.72 dB, 4.94 dB, and 7.077 dB, respectively. However, the obtained gain levels remain relatively low in terms of the high performance requirements of 5G communication standards. Additionally, the Rogers RO/4003C substrate material used in antenna fabrication, while offering high dielectric performance, poses a cost disadvantage. In another study by Hussain et al. [6], an umbrella-shaped microstrip-fed patch antenna with resonance frequencies at 28 GHz, 38 GHz, and 55 GHz was designed. This antenna features a compact size of 8 × 8 × 0.79 mm³. The gains at the resonant frequencies are 6.8 dBi, 7.15 dBi, and 7.4 dBi, respectively. The substrate material employed in this study is Rogers RT/Duroid 5870, which is also associated with high manufacturing costs. In a different multiband antenna study [7], an octagonal circular ring-shaped monopole antenna with dimensions of 20.27 × 16.76 × 1 mm³, applicable to C, X, Ku, K, and Ka band communication systems, was presented. This antenna exhibits nine distinct resonant frequencies. As noted by the authors, the antenna suffers from relatively large size and low gain issues.

Venkateshkumar et al. [4] proposed two different multiband microstrip patch antenna designs. The first design operates within WiFi-WLAN frequency bands, whereas the second, designed for mmWave bands, resonates at 14.6 GHz, 23.3 GHz, and 28.9 GHz, with dimensions of 17 × 17 × 0.787 mm and a gain of 5.4 dBi. The gain achieved in the mmWave band in this study is insufficient for high-frequency applications. In the antenna study presented in [8], a four-band dielectric resonator antenna (QD-DRA) operating at mmWave frequencies with dimensions of 12 × 11 × 0.25 mm³ was proposed for 5G applications. The antenna operates at 28 GHz, 34 GHz, 38 GHz, and 42 GHz, providing gains of 6.92 dBi, 7.4 dBi, 8.59 dBi, and 7.57 dBi, respectively. Unlike other multiband antenna studies, Ahmad et al. [9] designed a compact patch antenna integrated into a smartwatch for wearable applications. The antenna has dimensions of 4 × 3 × 0.25 mm³, and a coplanar waveguide (CPW) feeding technique was employed to maintain compactness. The antenna achieves gains of 5.29 dB, 7.47 dB, and 9 dB at frequencies of 28 GHz, 38 GHz, and 60 GHz, respectively. However, although it is noted that high-frequency usage in wearable applications may have adverse effects on human health, these effects were not addressed in detail in the study [9,10]. In the another study by Aylapogu and Gurrala [11], a multiband spider-shaped microstrip patch antenna with dimensions of 12.5 × 13.5 × 0.8 mm³, suitable for 5G and underwater communications, was designed. The authors indicated that this antenna could assist in determining the quality of underground water. The proposed antenna operates at frequencies of 10.16 GHz, 30.08 GHz, 36.08 GHz, and 41.3 GHz, achieving a maximum gain of 9.1 dBi. However, the use of Rogers RT/Duroid 5880 as the substrate material results in high production costs.

In another study [12], a multi-slotted microstrip patch antenna design was proposed for mmWave 5G communication devices. The antenna was designed on a Rogers RT5880 dielectric substrate with dimensions of 20 mm × 16.5 mm and operates at resonant frequencies of 28.05 GHz, 31.70 GHz, and 37.924 GHz. The proposed antenna achieves gain values of 9.15 dBi, 7.48 dBi, and 12.08 dBi, respectively, along with S11 values of –19.53 dB, –17.92 dB, and –21.34 dB. While the antenna demonstrates good performance due to its multi-band functionality, further enhancement of the bandwidth could allow the design to cover a broader range of future 5G frequency bands. In a different approach to enhance antenna performance, Hossain et al. [13] proposed a microstrip patch antenna integrated with a split square-shaped double negative metamaterial (DNMTM). The DNMTM structure, consisting of silver resonators on a quartz substrate, plays a critical role in improving the electromagnetic characteristics of the antenna. The antenna, composed of three layers (copper ground plane, quartz substrate, and copper patch), operates at 35.22 GHz, 43.25 GHz, and 47.70 GHz, achieving gains of 8.64 dBi, 7.80 dBi, and 7.47 dBi, respectively. While these gain values are satisfactory, further enhancement may be achieved through optimization of design parameters and material properties.

In study [14], a compact tri-band circular microstrip patch antenna for 5G mm-Wave and WiGig applications is proposed. The antenna is built on a three-layer dielectric substrate comprising Rogers RT/Duroid 5880 and Taconic RF-43, with overall dimensions of 10 × 10 × 0.6 mm³. Dual symmetrical slits on the radiating patch were systematically optimized, resulting in tri-band resonance at 28.3 GHz, 41.5 GHz, and 61.6 GHz, with corresponding bandwidths of 2.3 GHz, 8.11 GHz, and 11.03 GHz. Simulation results indicate peak gains of 7.05, 7.28, and 6.39 dBi. Despite achieving satisfactory bandwidth, the multilayer configuration and use of multiple dielectric materials may present fabrication and cost challenges.

The proposed antenna operates at center frequencies of 26.3 GHz, 28.48 GHz, 34.71 GHz, 37 GHz, 39.3 GHz, and 42.8 GHz and was designed and analyzed using the Computer Simulation Technology (CST) simulation software. Compared with other microstrip patch antennas, the proposed antenna exhibits higher gain, multiband operation, compactness, and a low-profile design while maintaining geometric simplicity. This unique combination of features enhances design flexibility and performance, setting it apart from previous studies. The remainder of the paper is organized as follows: Section 2 details the design stages of the proposed multiband antenna. Section 3 comprehensively discusses the analyzed simulation results of the antenna. Section 4 presents a comprehensive evaluation of the study, and the obtained results are comparatively analyzed with other related studies in the literature.

2. Material and Methods

In this study, a multiband microstrip patch antenna operating in the mmWave bands is presented. The proposed antenna consists of an elliptically shaped central patch, two symmetrically positioned ring elements on both sides, a microstrip transmission line, and a feeding line. The unique "turtle-shaped" geometry of the proposed antenna is illustrated in Figure 1. The ground plane, located on the rear side of the dielectric substrate, is designed to cover the entire surface to effectively guide the electromagnetic fields. The antenna is designed with dimensions of 32 mm × 14 mm × 0.381 mm using Taconic TLY-5 substrate material, which has a relative dielectric constant (ε_r) of 2.2 and a loss tangent (tanδ) of 0.0009. The TLY-5 substrate was selected due to its advantages such as low dielectric constant and high surface quality, enabling low propagation delay, reduced dielectric losses, and wide bandwidth performance in microwave and mmWave frequency bands [15]. In the antenna design, four half-circular slots are symmetrically etched on the main patch in pairs. These slots enable the antenna to operate at multiple resonant frequencies, significantly enhancing impedance matching and bandwidth. A microstrip feeding technique is employed for signal excitation. This feeding method offers advantages such as low transmission loss at high frequencies, ease of integration with printed circuit boards (PCBs), and high reproducibility in manufacturing processes [16].

The proposed antenna design was simulated using CST Microwave Studio (CST MWS) software (CST, 2024). In the simulation, open boundary conditions were applied in the X, Y and Z directions to model free-space conditions and suppress unwanted reflections from the boundaries. The frequency domain solver was employed along with a tetrahedral mesh, which provides higher accuracy for complex geometries compared to structured mesh methods.

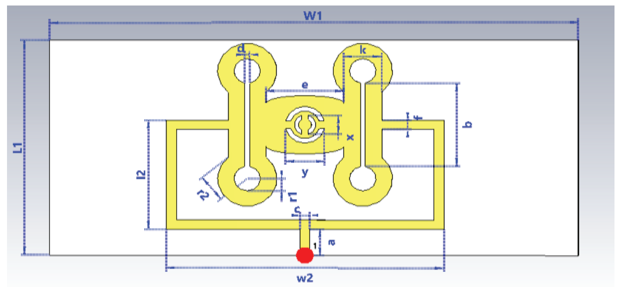

Figure 1. Simulated design of mmWave multiband antenna.

The design process comprises four main stages and the evolution of the proposed antenna design is illustrated in Figure 2, with the corresponding S11 results presented in Figures 3 and 4.

In the first stage (Design 1), the antenna structure was developed based on the combination of a single loop and two rectangular patch elements. This loop and patch configuration has been employed in numerous studies reported in the literature [17,18,19]. Simulation results at this stage indicate the presence of three distinct bands below –10 dB, with the widest bandwidth measured at 0.5 GHz. In the second stage (Design 2), a second loop element was incorporated, transforming the structure into a two-loop + one-patch configuration. The purpose of this modification is to enable the fractal elements to contribute to different resonant frequencies and to interact strongly at nearby frequencies, thereby achieving wider impedance bands. The literature emphasizes that fractal configurations can be effective in providing multiband performance [20]. At this stage, six distinct bands below –10 dB were obtained, with the widest bandwidth measured at 1.1 GHz.

In the third stage (Design 3), ellipticity was introduced to the edges of the patch element. According to the literature, such geometrical modifications are widely employed to enhance antenna performance parameters, including gain and multiband operation [21]. This structural modification led to improvements in the S11 characteristics of the antenna. Simulation results demonstrate the formation of six distinct operating bands below –10 dB, with the widest bandwidth achieved being 1.1 GHz. In the final stage (Design 4), four half-circular slots were symmetrically incorporated into the patch structure. The use of slots is a widely employed and effective technique for enhancing the bandwidth of narrowband patch antennas [22]. At this stage, six distinct bands below –10 dB were achieved, with the widest bandwidth measured at 1.4 GHz.

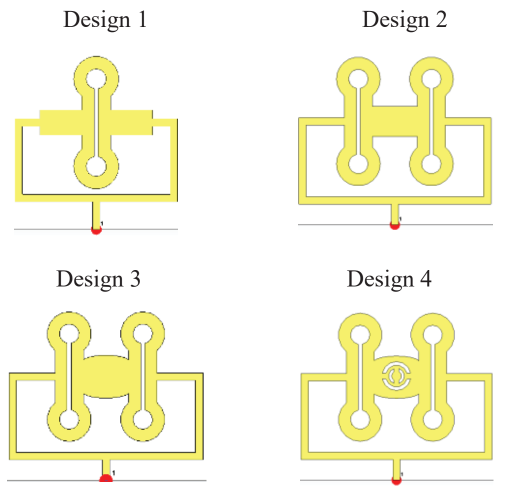

Figure 2. Design evolution steps of proposed antenna.

In Figure 3, the S11 parameters of Design 1 and Design 2 are presented to illustrate the effect of the fractal on the antenna performance. In Figure 4, the S11 parameters of Design 2,3, and 4 are shown for a comprehensive comparison of the successive design evolution steps.

As observed in Figure 3, the addition of the loop improves the S11 characteristics of the antenna and enables multiband operation. Figure 4 demonstrates that the incorporation of elliptical features into the design has led to noticeable improvements in the S11 values. Furthermore, the use of circular slots has increased the bandwidth and enhanced the S11 performance at specific frequency points.

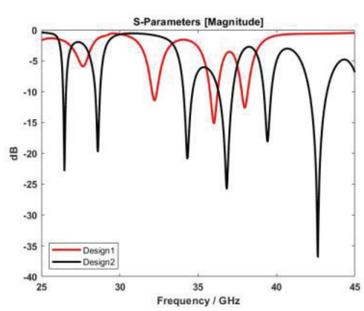

Figure 3. Design 1 and 2 evolution S11 results.

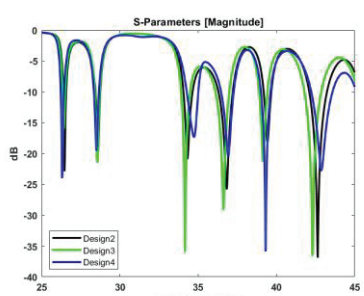

Figure 4. Design 2, 3 and 4 evolution S11 results.

The transmission line was optimized to provide a characteristic impedance of 50 Ω. The fundamental dimensions of the proposed microstrip antenna were calculated using widely accepted microstrip antenna design equations from the literature [23]. Parametric studies were conducted during the simulation process to maximize antenna performance, and design variables were optimized accordingly. The optimized dimensions of the antenna are presented in Table 1.

Table 1. Parametric dimensions of the designed antenna.

Parameter	**W1**	**L1**	**a**	**b**	**c**	**d**	**e**	**l2**
Value (mm)	32	14	1.7	5.43	0.6	0.3	4.7	7.1
Parameter	**f**	**k**	**x**	**y**	**w2**	**r1**	**r2**	**h**
Value (mm)	0.6	2.3	1.24	2.35	16.8	0.8	1.8	0.381

3. Results

The simulations of the proposed multiband antenna were conducted using CST MWS. Key performance metrics, including S11, radiation pattern, gain, and VSWR were thoroughly analyzed. Figure 5 illustrates the S11 of the microstrip antenna in decibels (dB) at the specified center frequencies. According to the simulation results, the antenna achieved S11 values of -24 dB, -19.06 dB, -17.29 dB, -20.27 dB, -35.87 dB, and -22.66 dB at center frequencies of 26.3 GHz, 28.48 GHz, 34.71 GHz, 37 GHz, 39.3 GHz, and 42.8 GHz, respectively. The obtained S11 values being below −10 dB indicate that more than 90% of the input power is delivered to the antenna, effectively minimizing reflection losses. The proposed antenna demonstrates its widest bandwidth of 1.4 GHz (42.2–43.6 GHz) at the 42.8 GHz center frequency. Although the operating bandwidths of the antenna are relatively narrow, narrowband antenna structures also offer significant advantages for communication applications.

Specifically, in high-frequency communication systems, narrow bandwidth effectively suppresses unwanted frequency components and interference, thereby enhancing signal quality. This not only contributes to the reduction of electromagnetic interference (EMI) but also improves the signal-to-noise ratio (SNR), facilitating more stable and reliable data transmission [24].

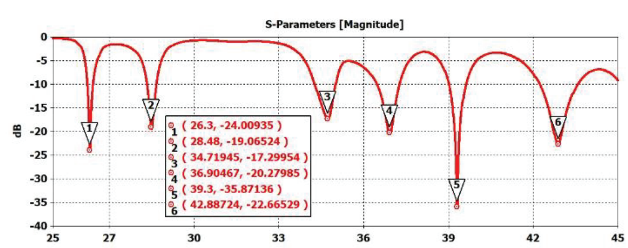

Figure 5. The simulation results of the S11 parameters with frequency of designed antenna.

Figure 6 presents the VSWR values at different center frequencies. According to the simulation results, the VSWR values at the center frequencies were found to be 1.13, 1.23, 1.31, 1.21, 1.03, and 1.16, respectively. VSWR is a parameter used to quantitatively assess the impedance matching between the transmission line and the antenna, with an ideal value close to one [25]. The obtained data indicate that the VSWR values at all center frequencies remain below 2. Notably, the VSWR values at 26.3 GHz and 39.3 GHz are very close to unity, implying minimal loss and excellent impedance matching at these frequencies. These results demonstrate that the proposed antenna performs efficiently under multiband operation conditions.

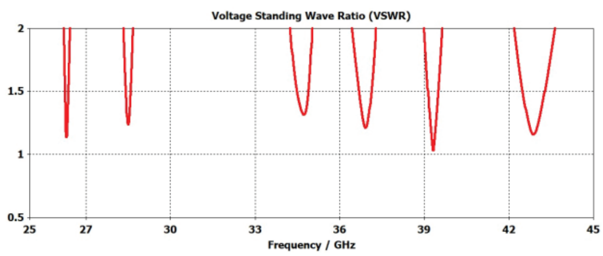

Figure 6. The simulation results of the VSWR values with frequency of designed antenna.

Figure 7 presents the gain performance of the antenna as a function of frequency. The proposed design operates over the 26.3–42.7 GHz band, achieving gain values ranging from 6.84 dBi to 10.52 dBi. The maximum gains are observed at 37.0 GHz (10.03 dBi) and 39.3 GHz (10.52 dBi). These results confirm that the antenna provides high gain across the mmWave spectrum, demonstrating its suitability for multiband applications.

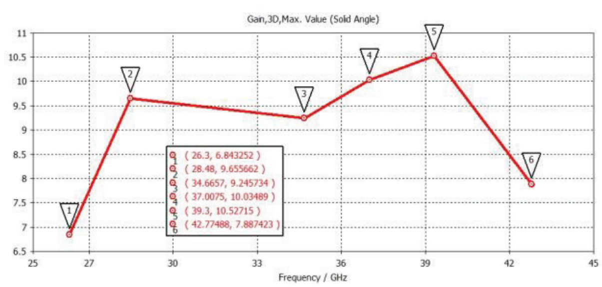

Figure 7. The simulation result of the Frequency-Gain Graph

The S11, VSWR, and gain values of the proposed antenna can be summarized as shown in Table 2.

Table 2. S11, VSWR and Gain values of designed antenna.

Frequency (GHz)	S11 (dB)	VSWR	Gain (dBi)
26.3	-24	1.13	6.84
28.48	-19.06	1.23	9.65
34.71	-17.29	1.31	9.24
37	-20.27	1.21	10.03
39.3	-35.87	1.03	10.52
42.8	-22.66	1.16	7.88

The simulation results of the one-dimensional (1D) and three-dimensional (3D) radiation patterns of the designed antenna in the YZ plane are summarized in Figure 8 and Figure 9 at the corresponding center frequencies.

The evaluated frequency points are 26.3 GHz, 28.48 GHz, 34.71 GHz, 37 GHz, 39.3 GHz, and 42.8 GHz. The main beam directions corresponding to these frequencies are found to be 46°, 32°, 40°, 16°, 56°, and 52° respectively. Similarly, the 3 dB beamwidths are calculated as 43.5°, 38.7°, 31.5°, 24.2°, 41.9°, and 41.7°. Finally, the antenna gains obtained at the respective frequencies are 6.84 dBi, 9.65 dBi, 9.24 dBi, 10.03 dBi, 10.52 dBi, and 7.88 dBi. The proposed antenna exhibits considerably high gain performance, with values of 10.03 dBi (@ 37 GHz) and 10.52 dBi (@ 39.3 GHz).

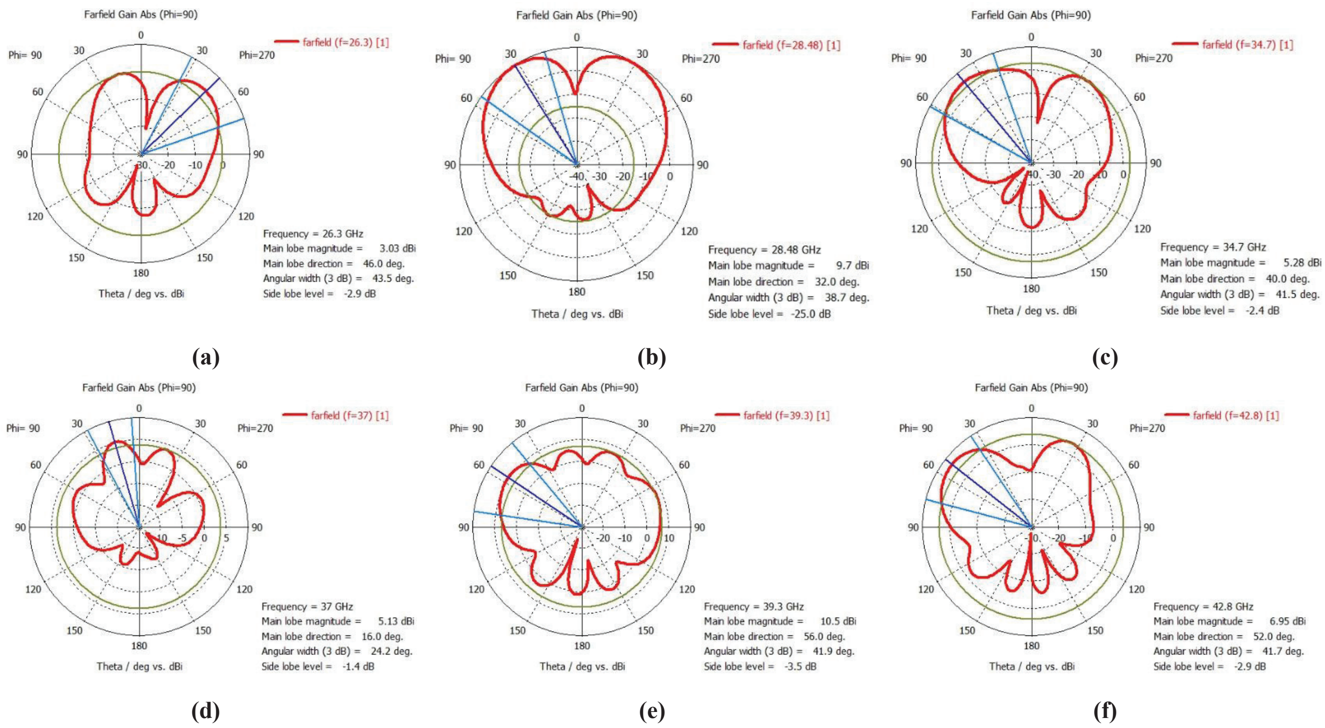

Figure 8. 1D Farfield Pattern of designed antenna.

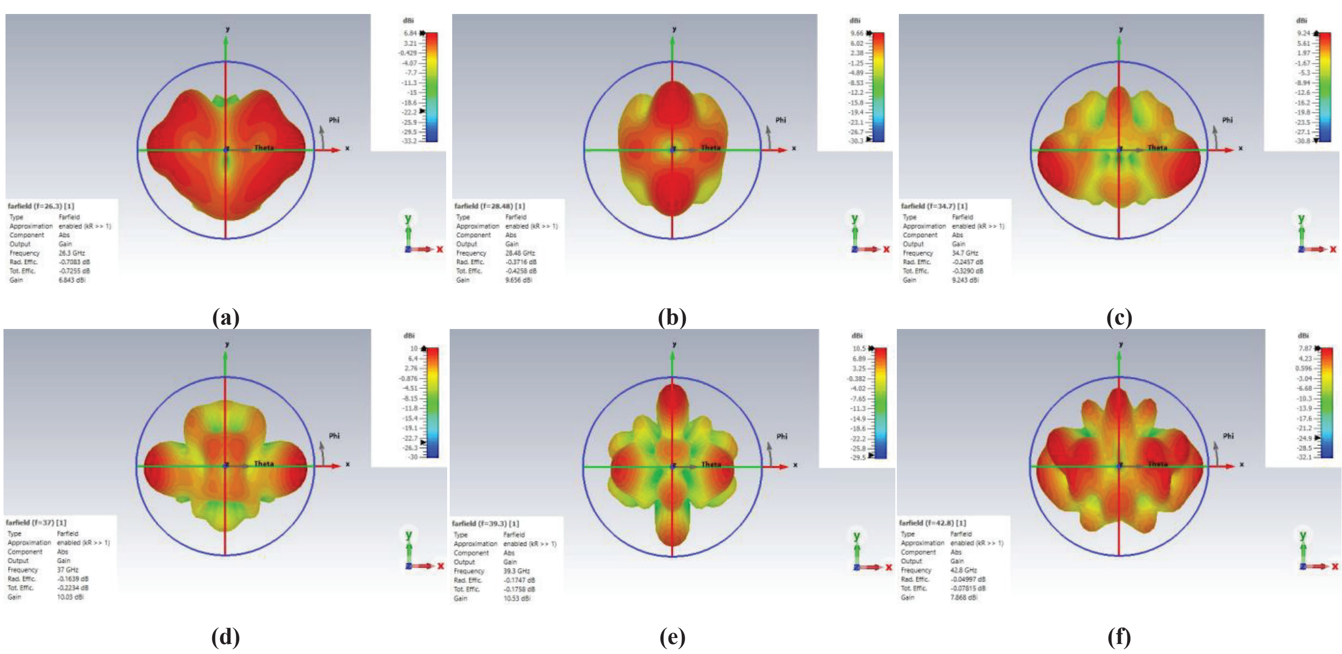

Figure 9. 3D Farfield Pattern of designed antenna.

Table 3. Performance Comparative Analysis of Multiband Antennas.

Ref.	Antenna Dimensions (mm)	Operating Frequency (GHz)	S11 (dB)	Substrate Material	Peak Gain (dBi)	VSWR
[5]	16.5 x16.5	10, 13, 17, 26	-28.17, -15, -20.32, -57.15	Rogers RO/ 4003C	7.07	—
[6]	8x8	28, 38, 55	~ -25, ~ -30, ~ -20	Rogers RT/Duroid 5870	7.4	—
[7]	20.27x16.76	6.3, 9.8, 16.3, 19.1, 22.9, 26.6, 31, 35.2, 39.5	-30.1, -21.5, -26.2, -19.8, -22, -24.8, -28, -19.5, -20.2	Rogers RT/ Duroid 5880	9.32	—
[8]	17x17	14.6, 23.3, 28.9	-37.8, -15.5, -30.4	FR-4	5.4	1.02
[9]	12x11	28, 34, 38, 42	~ -20, ~ -20, ~ -20, ~ -25	Rogers RT/Duroid 5880	8.59	—
[10]	4x3	28, 38, 60	~ - 22.5, ~ -40, ~ -20	Rogers RT/Duroid 5880	9	—
[15]	12.5x13.5	10.16, 30.08, 36.08, 41.3	-11.18, -20.87, - 21.34, - 21.32	RT/Duroid 5880	9.1	1.69
This work	32x14	26.3, 28.48, 34.71, 37, 39.3, 42.8	-24, -19.06, -17.29, -20.27, -35.87, -22.66	Taconic TLY-5	10.52	1.03

The obtained 1D and 3D far-field radiation patterns reveal that the proposed antenna demonstrates successful performance in key parameters particularly within the mmWave frequency bands (K, Ka and lower V bands). Owing to its narrow main lobe structure, the radiation is effectively concentrated in a specific direction, thereby enhancing beam steering accuracy. This characteristic significantly contributes to signal transmission over long distances without substantial attenuation. Although microstrip patch antennas are generally known for limitations such as low efficiency and gain, the proposed design in this study demonstrates a remarkable level of gain performance [26]. Considering similar studies in the literature, the proposed antenna design demonstrates high gain and acceptable VSWR values. The results of this study are comparatively summarized with selected works from the literature in Table 3.

In [27] mmWave frequencies have been widely reported for use in various application areas. In particular, mmWave frequencies are commonly employed in 5G communication systems in dense urban environments to provide high data rates and low latency. On the other hand, the Ka-band (27-40 GHz) is preferred for satellite communications, unmanned aerial vehicle applications, and radar systems, offering long-range and high-capacity connections. The 28 GHz and 60 GHz bands are also prominent for wearable devices and body-centric communication systems, enabling high-speed data transmission and biomedical monitoring. In this context, the operating bands of the proposed multiband antenna within the 26–42 GHz frequency range exhibit potential applicability across numerous application areas reported in the literature.

4. Conclusions

In this study, a multiband and high-gain patch antenna employing a microstrip feed line, suitable for 5G applications, is presented in detail. The proposed antenna has been designed and analyzed using CST software. Key performance parameters that characterize the antenna's operational behavior, such as the retuen parameter, VSWR, and Far-field radiation patterns, have been thoroughly investigated. The designed patch antenna exhibits low S11 values at the resonant frequencies of 26.3 GHz, 28.48 GHz, 34.71 GHz, 37 GHz, 39.3 GHz, and 42.8 GHz, with corresponding S11 measurements of -24 dB, -19.06 dB, -17.29 dB, -20.27 dB, -35.87 dB, and -22.66 dB, respectively. The antenna dimensions have been optimized to $32 \times 14 \times 0.381$ mm³, which makes the proposed design highly suitable for compact 5G system integration. Moreover, the antenna demonstrates notable gain values of 6.84 dBi, 9.65 dBi, 9.24 dBi, 10.03 dBi, 10.52 dBi, and 7.88 dBi across the aforementioned frequency bands, indicating its high-gain performance.

5. References

[1] S. Punith, S. K. Praveenkumar, A. A. Jugale, and M. R. Ahmed, "A novel multiband microstrip patch antenna for 5G communications", Procedia Computer Science, vol. 171, pp. 2080–2086, 2020.

[2] D. H. Patel and G. D. Makwana, "A comprehensive review on multi-band microstrip patch antenna comprising 5G wireless communication", International Journal of Computing and Digital System, 2021.

[3] J. Zhang and J. Mao, "A high-gain Ka-band microstrip patch antenna with simple slot structure", International Conference on Microwave and Millimeter Wave Technology (ICMMT), 2020.

[4] U. Venkateshkumar, S. Kiruthiga, H. Mihitha, K. Maheswari, and M. Nithiyasri, "Multiband patch antenna design for 5G applications", International Conference on Computing Methodologies and Communication (ICCMC), 2020, pp. 528–534.

[5] D. H. Sadek, H. A. Shawkey, and A. A. Zekry, "Multiband triple L-arms patch antenna with diamond slot ground for 5G

applications", Applied Computational Electromagnetics Society Journal (ACES), vol. 36, pp. 302–307, 2021.

[6] M. Hussain, S. M. R. Jarchavi, S. I. Naqvi, U. Gulzar, S. Khan, M. Alibakhshikenari, and I. Huynen, "Design and fabrication of a printed tri-band antenna for 5G applications operating across Ka- and V-band spectrums", Electronics, vol. 10, 2021.

[7] A. S. Faris and M. M. Tulu, "Design and performance analysis of multi-band antenna for 5G application", Wireless Personal Communications, vol. 136, pp. 429–452, 2024.

[8] M. Sana, S. Ahmad, F. Abrar, and M. A. Qasim, "Millimeter-wave quad-band dielectric resonator antenna for 5G applications", International Conference on Smart Technologies, 2021, pp. 304–307.

[9] S. Ahmad, A. Ghaffar, X. J. Li, and N. Cherif, "A millimetre-wave tri-band antenna embedded on smart watch for wearable applications", International Symposium on Antennas and Propagation (ISAP), 2021.

[10] S. Kim, Y. A. Sharif, and I. Nasim, "Human electromagnetic field exposure in wearable communications systems: A review", e-Prime–Advances in Electrical Engineering, Electronics and Energy, vol. 8, 2024.

[11] P. K. Aylapogu and K. K. Gurrala, "MM wave based multiband spider slot patch antenna for 5G and underwater communication", Microsystem Technologies, vol. 29, pp. 1547–1556, 2023.

[12] M. Nahas, "A multi-slotted multi-band microstrip patch antenna design for 5G communication devices", Engineering, Technology & Applied Science Research, vol. 15, pp. 24605–24610, 2025.

[13] M. A. Uddin, M. J. Hossain, A. Shaha, M. N. Hossain, A. K. Chakrabarty, and M. H. Baharuddin, "Double negetive metamaterial-embedded microstrip patch antenna for Ka and V-band applications", International Conference on Advancement in Electrical and Electronic Engineering (ICAEEE), 2024.

[14] F. M. Abdo, A. S. Gaid, M. M. Saeed, R. A. Saeed, and M. A. Alomari, "Tri-band circular microstrip patch antenna with slits and multilayered substrate for 5G mmWave communications", International Conference on Emerging Smart Technologies and Applications (eSmarTA), 2025.

[15] R. A. Fayadh, F. Malek, and H. A. Fadhil, "Spade-shaped patch antenna for ultra wideband wireless communication systems", International Journal of Advanced Computer Research, vol. 3, pp. 16–22, 2013.

[16] R. Erxleben, I. Ndip, L. Brusberg, H. Schröder, M. Töpper, W. Scheel, S. Guttowski and H. Reichl, "A comparative study of microstrip, stripline and coplanar lines on different substrate technologies for high-performance applications", International Symposium on Microelectronics, 2009.

[17] K. Ding, C. Gao, D. Qu, and Q. Yin, "Compact broadband circularly polarized antenna with parasitic patches", IEEE Transactions on Antennas and Propagation, vol. 65, pp. 4854–4857, 2017.

[18] R. Hasse, W. Hunsicker, K. Naishadham, A. Z. Elsherbeni, and D. Kajfez, "Analysis and design of a partitioned circular loop antenna for omni-directional radiation", International Symposium on Antennas and Propagation (APSURSI), 2011, pp. 1379–1382.

[19] H. Lee and Y. M. Lim, "Printed dual ring loop antenna for wide-dual-frequency band of wireless applications", Microwave and Optical Technology Letters, vol. 54, pp. 1317–1318, 2012.

[20] U. S. Modani and A. Jain, "A literature review of multi-frequency microstrip patch antenna designing techniques", International Journal of Research in Engineering, IT and Social Sciences, vol. 7, pp. 41-45, 2017.

[21] J. V. Jose, A. S. Rekh, and M. J. Jose, "Design techniques for elliptical microstrip patch antenna and their effects on antenna performance", International Journal of Innovative Technology and Exploring Engineering, vol. 8, pp. 2317–2326, 2019.

[22] K. R. Xiang and F. C. Chen, "A method for increasing the bandwidth of slot and patch antennas using grid-slotted patch", International Journal of RF and Microwave Computer-Aided Engineering, vol. 31, 2021.

[23] C. A. Balanis, Antenna Theory: Analysis and Design, John Wiley & Sons, USA, 2016.

[24] A. S. Abd El-Hameed, D. M. Elsheakh, G. M. Elashry, and E. A. Abdallah, "A comparative study of narrow/ultra-wideband microwave sensors for the continuous monitoring of vital signs and lung water level", Sensors, vol. 24, 2024.

[25] P. O. Otasowie and E. A. Ogujor, "Voltage standing wave ratio measurement and prediction", International Journal of Physical Sciences, vol. 4, pp. 651–656, 2009.

[26] A. Bansal and R. Gupta, "A review on microstrip patch antenna and feeding techniques", International Journal of Information Technology, vol. 12, pp. 149–154, 2020.

[27] F. Mehmood and A. Mehmood, "Recent advancements in millimeter-wave antennas and arrays: From compact wearable designs to beam-steering technologies", Electronics, vol. 14, 2025.

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