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High-Gain Microstrip Patch Antenna for Satellite and Radar Applications

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Abstract

The growing demand for high-speed wireless communication, satellite connectivity, and advanced radar systems has increased the necessity for compact and high-performance antenna designs. This study presents the design and analysis of a high-gain microstrip patch antenna intended for satellite and radar applications operating in the microwave frequency range. The proposed antenna structure is developed using a low-loss dielectric substrate to enhance radiation efficiency, bandwidth, and gain characteristics while maintaining a compact profile. Various antenna parameters such as return loss, voltage standing wave ratio (VSWR), radiation pattern, bandwidth, and gain are investigated through electromagnetic simulation techniques. The antenna incorporates optimized patch dimensions and feeding mechanisms to achieve improved directional radiation and reduced signal loss. Simulation results demonstrate that the proposed antenna achieves high gain, stable impedance matching, and superior radiation performance suitable for long-distance communication and target detection systems. The compact geometry and lightweight structure make the antenna highly suitable for integration into modern aerospace, defense, and wireless communication platforms. The antenna also shows improved operating stability in a range of environmental and frequency conditions. The study concludes that the designed microstrip patch antenna offers an efficient and cost-effective solution for next-generation satellite communication and radar technologies requiring reliable high-frequency performance.

Keywords: Microstrip patch antenna, high gain, satellite communication, radar systems, microwave frequency, wireless communication

INTRODUCTION

The rapid advancement of wireless communication technologies, satellite networks, aerospace systems, and modern radar applications has significantly increased the demand for efficient, compact, and high-gain antenna systems capable of operating at microwave and radio frequencies with superior performance characteristics. Among the various antenna configurations available for high-frequency communication systems, the microstrip patch antenna has emerged as one of the most preferred antenna structures owing to its lightweight nature, low manufacturing cost, planar profile, ease of fabrication, and compatibility with integrated circuits and printed circuit board technologies. In recent years, satellite communication and radar systems have become fundamental components in military, aerospace, meteorological, navigation, remote sensing, and wireless communication infrastructures, thereby creating the necessity for antennas that can provide enhanced gain, wider bandwidth, improved radiation efficiency, low return loss, and stable impedance matching under varying operational conditions. Conventional antennas often face challenges such as bulky structures, high power consumption, and integration difficulties, which limit their suitability for compact and portable electronic systems. To overcome these limitations, researchers have focused extensively on the development of advanced microstrip patch

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antenna designs capable of achieving high directional gain and reliable signal transmission while maintaining compact dimensions and low-profile configurations. High-gain microstrip patch antennas are particularly advantageous for satellite and radar applications because they improve signal strength, increase communication range, reduce transmission losses, and enhance target detection accuracy in complex environments. The demand for high-frequency satellite communication systems operating in C-, X-, Ku-, and Ka-band frequencies has further accelerated research on optimized patch geometries, feeding techniques, substrate materials, and array configurations to improve antenna performance metrics. In radar systems, antenna gain plays a critical role in determining the detection range, angular resolution, and signal-to-noise ratio, making high-gain antennas essential for defense surveillance, weather monitoring, air traffic control, and automotive radar applications. Microstrip patch antennas can be designed in various shapes, such as rectangular, circular, triangular, elliptical, and fractal geometries, depending on the desired operational frequency and radiation characteristics. Among these geometries, the rectangular microstrip patch antenna is widely adopted because of its simple structure, ease of analysis, and effective radiation properties. However, traditional microstrip patch antennas inherently suffer from limitations such as narrow bandwidth and relatively low gain, which restrict their direct application in advanced satellite and radar systems. Therefore, several enhancement techniques, including the use of parasitic elements, stacked patches, defected ground structures, electromagnetic band-gap structures, metamaterials, slot loading, and antenna arrays, have been proposed to improve antenna gain and bandwidth performance. The choice of dielectric substrate material also significantly influences antenna efficiency, bandwidth, radiation pattern, and resonant frequency stability. Low-loss substrates with optimized dielectric constants are commonly utilized to reduce dielectric losses and improve overall antenna performance at microwave frequencies.

Figure 1 illustrates the complete flowchart of the design methodology adopted for the proposed high-gain microstrip patch antenna intended for satellite and radar applications. The design process begins with the specification stage, where important antenna requirements such as operating frequency, gain, bandwidth, return loss, and voltage standing wave ratio (VSWR) are determined according to system needs. The next stage involves substrate selection, where a low-loss dielectric material with a suitable dielectric constant and thickness is chosen to improve radiation efficiency and reduce signal losses. Subsequently, the initial patch dimensions and ground plane sizes are calculated to achieve resonance at the desired microwave frequency. The feeding network design stage defines the microstrip line feed dimensions for proper impedance matching and efficient power transfer. Parametric optimization is then performed to refine antenna dimensions and improve gain, bandwidth, and radiation characteristics. Electromagnetic simulation and analysis were carried out using MATLAB and RF simulation tools to evaluate antenna parameters such as S-parameters, radiation pattern, efficiency, and gain. If the obtained results do not satisfy the required specifications, the design is re-optimized iteratively. Finally, the validated antenna structure achieving high gain and stable performance was confirmed as the optimized microstrip patch antenna design suitable for advanced satellite and radar communication systems.

Furthermore, modern computational electromagnetic simulation tools, such as CST Microwave Studio, HFSS, FEKO, and ADS, have enabled precise antenna modeling and optimization, allowing researchers to analyze parameters, including return loss, voltage standing wave ratio (VSWR), gain, directivity, radiation efficiency, and current distribution, before fabrication. The integration of high-gain microstrip patch antennas into satellite systems enables reliable long-distance communication links, high data-rate transmission, and robust signal reception under adverse atmospheric conditions. Similarly, in radar systems, these antennas facilitate precise object detection, tracking, imaging, and navigation functionalities by providing highly directional radiation patterns and reduced interference levels. With the emergence of fifth-generation (5G) and future sixth-generation (6G) communication systems, the significance of compact high-frequency antennas has further increased owing to the requirement for high-speed data transfer, low latency, and spectrum efficiency.

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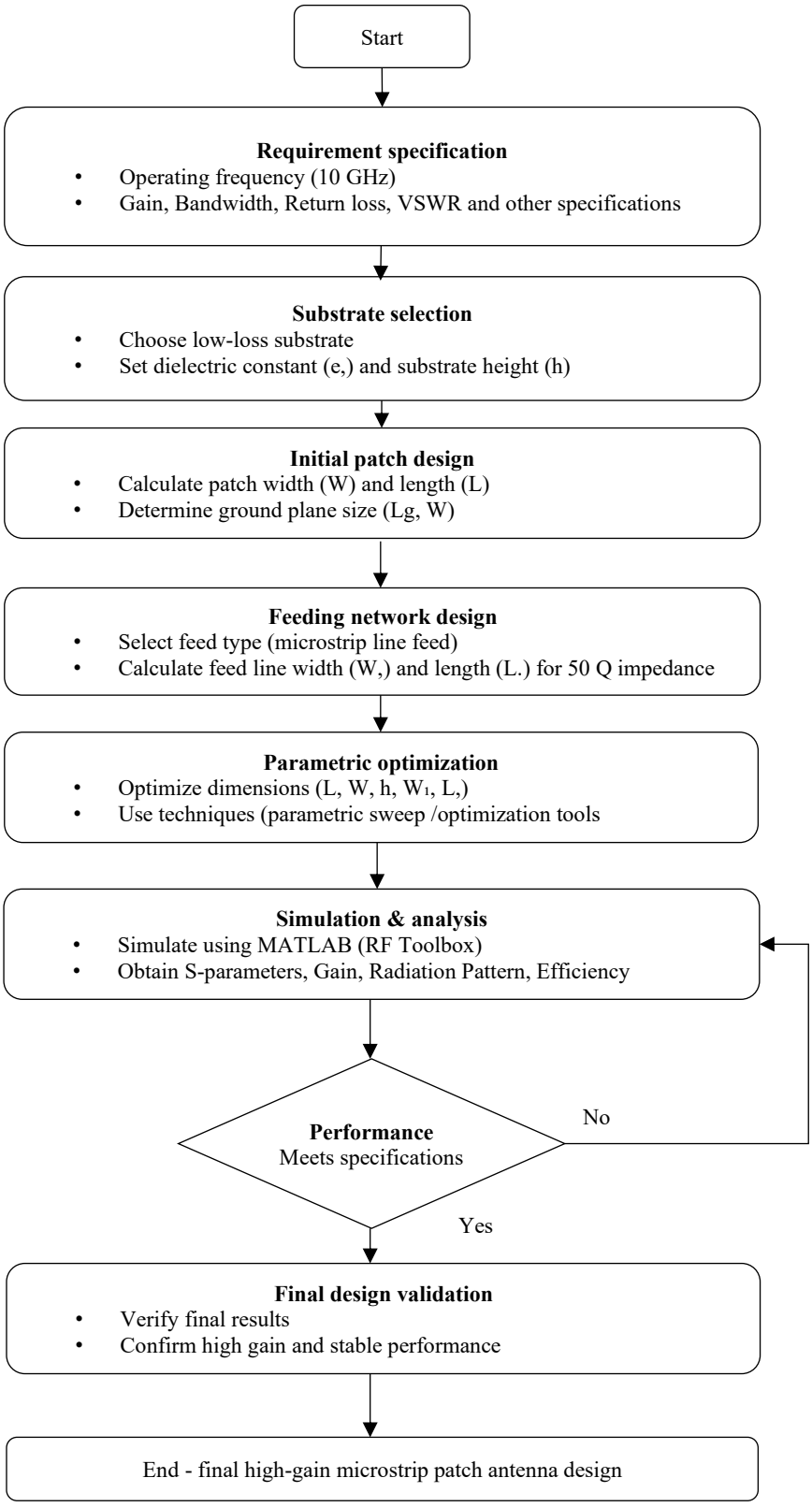


Figure 1. Flowchart of the design process for the proposed high-gain microstrip patch antenna.

Additionally, advancements in unmanned aerial vehicles (UAVs), autonomous vehicles, Internet of Things (IoT) devices, and smart defense systems have created new opportunities for the deployment of high-performance microstrip antennas in compact electronic platforms. Researchers are also exploring

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reconfigurable and beam-steering antenna technologies to improve adaptability and dynamic performance in rapidly changing communication environments. The development of high-gain microstrip patch antennas not only contributes to improved communication reliability and radar accuracy but also supports the miniaturization and integration of modern electronic systems. Moreover, the growing emphasis on energy-efficient and low-cost wireless technologies has encouraged the adoption of microstrip antennas owing to their reduced fabrication complexity and suitability for mass production using standard photolithographic techniques. Despite substantial progress in antenna research, achieving simultaneous enhancement in gain, bandwidth, efficiency, and compactness remains a challenging task that continues to attract significant academic and industrial interest. Consequently, continuous research efforts are directed toward innovative antenna structures and optimization methodologies capable of meeting the stringent requirements of next-generation satellite and radar communication systems. In this context, the present study focuses on the design and analysis of a high-gain microstrip patch antenna intended for satellite and radar applications. The proposed antenna aims to achieve superior gain characteristics, stable radiation patterns, improved impedance matching, and enhanced operational efficiency through optimized design parameters and advanced simulation techniques. The study also investigates the influence of antenna dimensions, feeding mechanisms, substrate selection, and ground plane configurations on the overall performance metrics. The outcomes of this research are expected to contribute to the development of efficient and compact antenna solutions suitable for modern aerospace, defense, wireless communication, and radar technologies requiring high-frequency and long-range operational capabilities.

LITERATURE REVIEW AND THEORETICAL ANALYSIS

The development of high-gain microstrip patch antennas has become a major research area owing to the increasing demand for compact, lightweight, and efficient communication systems in satellites, radar, aerospace, and wireless applications. Researchers have extensively investigated various antenna structures, substrate materials, feeding mechanisms, and gain enhancement techniques to overcome the inherent limitations of conventional microstrip antennas, such as narrow bandwidth, low radiation efficiency, and limited gain. Modern satellite communication and radar systems require antennas capable of operating at high frequencies with stable radiation characteristics, improved impedance matching, and enhanced signal transmission performance. Consequently, several innovative antenna designs and optimization methods have been proposed in recent years to satisfy the requirements of next-generation wireless systems. A compact high-gain microstrip antenna integrating 24 GHz and 77 GHz arrays for automotive radar and advanced communication applications [1]. Their work focused on achieving dual-frequency operation while maintaining compact dimensions and improved gain characteristics. The study demonstrated effective integration of multiple frequency bands and enhanced directional radiation performance. However, the proposed design suffered from increased structural complexity and fabrication challenges owing to the integration of compact high-frequency arrays. A high-gain X-band electromagnetic band gap (EBG) microstrip patch antenna for CubeSat applications was developed [2]. The authors utilized electromagnetic band gap structures to suppress surface wave losses and improve antenna gain and radiation efficiency. The proposed antenna achieved enhanced directional performance suitable for small satellite communication systems. Despite the improved gain performance, the antenna required precise fabrication and optimization of EBG structures, increasing implementation complexity in practical aerospace systems. Elahi et al. introduced a compact and high-gain 4 × 4 circularly polarized microstrip patch antenna array intended for next-generation small satellite applications [4]. Their research focused on achieving circular polarization, high radiation efficiency, and stable gain characteristics for reliable satellite communication. The antenna array demonstrated superior gain and reduced polarization mismatch losses compared to conventional designs. However, the increased number of array elements resulted in higher design complexity, larger feeding networks, and increased manufacturing costs. Gain enhancement techniques for microstrip patch array antennas using two metallic plates for 24 GHz radar applications [7]. The study revealed that metallic plate structures significantly improved antenna gain and directivity by reducing electromagnetic wave dispersion and enhancing radiation concentration. The proposed design was suitable for radar systems requiring accurate target detection and high-frequency operation.

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Nevertheless, the antenna exhibited bandwidth limitations and required careful alignment of metallic components to maintain optimal performance. A compact dual-band microstrip patch antenna for C-, X-, and Ku-band applications was proposed in previous studies [8]. Their antenna design provided multiband functionality suitable for satellite communication and radar systems operating across multiple microwave frequency bands. The proposed structure achieved compact size and improved impedance matching characteristics. However, the study identified reduced efficiency and gain degradation at higher operational frequencies, indicating the need for further optimization to achieve stable high-frequency performance. In addition to antenna-focused studies, related research in signal processing, integrated systems, and nonlinear communication analysis has contributed significantly to the advancement of modern RF and microwave technologies. A comprehensive study on multi-area hybrid power systems for generation control was conducted [3]. Their work emphasized intelligent optimization and system stability in advanced electrical systems, which are relevant to efficient power management in communication infrastructures. Although the study primarily focused on power systems, the findings highlighted the importance of stable control mechanisms for integrated communication and electronic platforms. AI-assisted conversion and optimization techniques for analog-to-digital signal transmission in low-power IoT and edge devices were discussed [5]. Their study demonstrated the role of artificial intelligence in improving signal accuracy, energy efficiency, and data transmission reliability in modern communication systems. The research indicated that AI-based optimization could enhance RF signal processing performance in compact wireless devices, although computational complexity and hardware integration challenges remained significant concerns. Physical design challenges and solutions for advanced three-dimensional integrated circuits (3D ICs) were investigated in the study [6]. Their research emphasized the importance of compact and efficient integration techniques in high-frequency electronic systems. The study identified thermal management, interconnect complexity, and packaging reliability as major challenges affecting the performance of advanced RF communication devices. A detailed review of system-in-package technologies and advanced packaging reliability for modern electronic systems was presented [9]. Their findings highlighted the significance of miniaturized packaging solutions in improving performance, integration density, and reliability of RF and microwave communication modules. However, issues related to thermal dissipation and electromagnetic interference remained critical challenges in high-frequency packaging technologies. Thermal analysis and optimization techniques for three-dimensional integrated circuits were investigated in the study [10]. The study demonstrated that thermal effects significantly influence the performance and reliability of high-frequency communication systems and RF devices. Efficient thermal optimization was identified as essential for maintaining antenna stability and signal integrity in compact electronic platforms. A fractal-entropy guided adaptive signal reconstruction technique for non-stationary biomedical and communication systems was investigated [11]. Their research focused on improving signal reconstruction accuracy and adaptive communication performance in complex environments. The findings suggested that advanced signal processing techniques could contribute to improved RF communication reliability and reduced transmission errors in dynamic wireless systems. Harmonic elimination in photovoltaic systems using multilevel inverter topologies [12]. Although centered on renewable energy systems, the study highlighted the importance of harmonic reduction and power quality improvement, which are also critical in RF communication circuits and antenna systems to minimize signal distortion and electromagnetic interference. Research was conducted on frequency parameter detection of frequency-shifted track circuits using nonlinear algorithms [13]. Their study demonstrated the effectiveness of nonlinear signal analysis techniques in improving frequency detection accuracy and communication reliability in complex systems. Nonlinear characteristics of GaN power switching devices through complex circuit simulations were analyzed [14]. Their findings revealed the importance of nonlinear modeling and high-frequency device optimization in achieving efficient RF system performance. Overall, the reviewed literature indicates that significant progress has been made in the development of high-gain microstrip patch antennas and related RF communication technologies. Existing studies have successfully improved antenna gain, compactness, radiation efficiency, and multiband functionality using advanced structures such as electromagnetic band gap materials, antenna arrays, metallic reflectors, and circular polarization techniques. However, several challenges remain unresolved, including narrow bandwidth, structural

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complexity, fabrication difficulty, thermal instability, and reduced efficiency at higher microwave frequencies. Furthermore, integration of compact high-gain antennas with advanced signal processing and intelligent communication systems continues to require further investigation. Therefore, there remains a strong need for the development of optimized microstrip patch antenna designs capable of simultaneously achieving high gain, compact structure, wide bandwidth, stable impedance matching, and efficient high-frequency performance for next-generation satellite and radar applications.

PROPOSED HIGH-GAIN MICROSTRIP PATCH ANTENNA

The proposed high-gain microstrip patch antenna was designed to achieve enhanced radiation performance, improved gain characteristics, stable impedance matching, and efficient operation for satellite and radar communication applications operating in the microwave frequency range. The antenna structure utilizes a compact rectangular microstrip patch configuration fabricated on a low-loss dielectric substrate to ensure high radiation efficiency and reduced transmission losses. The selection of the substrate material plays a critical role in determining the antenna performance; therefore, a substrate with an optimized dielectric constant and low tangent loss was employed to improve bandwidth and minimize dielectric dissipation at high frequencies. The proposed antenna consists of a radiating patch element, dielectric substrate, ground plane, and optimized feeding mechanism integrated into a compact planar structure suitable for lightweight and portable aerospace and defense systems. The rectangular patch dimensions were carefully calculated based on the desired resonant frequency using standard transmission line and cavity model equations to achieve accurate microwave operation. To enhance the antenna gain and directivity, the design incorporates parasitic elements and defected ground structures that suppress surface wave propagation and improve radiation concentration in the desired direction. In addition, slot optimization techniques were implemented on the patch surface to improve current distribution, bandwidth characteristics, and impedance matching performance. The feeding mechanism utilized a microstrip line feed technique owing to its simplicity, ease of fabrication, and compatibility with planar circuits, ensuring efficient power transfer between the transmission line and radiating element.

Width Calculation of Microstrip Patch Antenna:

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}}$$

$$W = \frac{3\times10^8}{2\times10\times10^9}\sqrt{\frac{2}{2.2+1}}$$

$$W = 0.015 \times \sqrt{\frac{2}{3.2}}$$

$$W = 0.015 \times 0.7905 = 11.86 \times 10^{-3}\ \text{m}$$

Effective Dielectric Constant Expression:

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[\frac{1}{\sqrt{1+12\frac{h}{W}}}\right]$$

$$\varepsilon_{eff} = \frac{2.2+1}{2} + \frac{2.2-1}{2}\left[\frac{1}{\sqrt{1+12\left(\frac{1.6}{11.8}\right)}}\right]$$

$$\varepsilon_{eff} = 1.6 + 0.6\left[\frac{1}{\sqrt{2.627}}\right]$$

$$\varepsilon_{eff} = 1.6 + 0.370 = 1.97$$

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The antenna is primarily intended for operation in the X-band and Ku-band frequency ranges, which are widely used in radar surveillance, satellite communication, weather monitoring, and aerospace applications. Electromagnetic simulation software, such as HFSS or CST Microwave Studio, is employed to analyze and optimize important antenna parameters, including return loss, voltage standing wave ratio (VSWR), gain, bandwidth, radiation pattern, directivity, and radiation efficiency. The proposed antenna is designed to achieve a return loss below −10 dB and a VSWR value close to unity, indicating excellent impedance matching and minimal reflection losses. The gain enhancement mechanism significantly improves the directional radiation performance compared to conventional microstrip patch antennas, enabling long-distance communication and accurate radar target detection. The radiation pattern of the antenna exhibits highly directional characteristics with reduced side lobe levels and improved signal concentration, which are essential for satellite and radar systems requiring reliable and focused signal transmission. The compact geometry and low-profile structure make the antenna highly suitable for integration into modern wireless devices, CubeSats, unmanned aerial vehicles, portable radar units, and advanced communication platforms.

Extension Length Due to Fringing Effect:

$$\Delta L = 0.412h\left(\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)}\right)$$

$$\Delta L = 0.412(1.6)\left(\frac{(1.97+0.3)\left(\frac{11.8}{1.6}+0.264\right)}{(1.97-0.258)\left(\frac{11.8}{1.6}+0.8\right)}\right)$$

$$\Delta L = 0.6592 \times \frac{2.27\times7.639}{1.712\times8.175}$$

$$\Delta L = 0.6592 \times 1.211 = 0.798 \text{ mm}$$

Actual Patch Length Calculation:

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} - 2\Delta L$$

$$L = \frac{3\times10^8}{2(10\times10^9)\sqrt{1.97}} - 2(0.798 \times 10^{-3})$$

$$L = \frac{3\times10^8}{28.07\times10^9} - 1.596 \times 10^{-3}$$

$$L = 10.69 \times 10^{-3} - 1.596 \times 10^{-3}$$

$$L = 9.09 \times 10^{-3} \text{ m} = 9.09 \text{ mm}$$

The proposed antenna also demonstrates stable operational performance under varying environmental and frequency conditions, making it appropriate for real-time aerospace and defense applications. Furthermore, the use of lightweight materials and planar fabrication techniques reduces manufacturing complexity and overall system cost while maintaining high electromagnetic performance. The proposed design overcomes many limitations of traditional microstrip antennas, such as low gain and narrow bandwidth, through optimized structural modifications and advanced electromagnetic enhancement techniques. The antenna is expected to provide improved communication reliability, enhanced radar detection accuracy, and efficient high-frequency operation for future satellite and microwave communication systems. Overall, the proposed high-gain microstrip patch antenna offers a compact, cost-effective, and high-performance solution for modern radar and satellite applications requiring superior gain, efficient radiation characteristics, and reliable microwave frequency operation.

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Table 1. Design parameters of the proposed high-gain microstrip patch antenna

S.N.	Parameter	Symbol	Value
1	Operating Frequency	f_r	10 GHz
2	Substrate Material	–	Rogers RT/Duroid 5880
3	Dielectric Constant	ε_r	2.2
4	Substrate Height	h	1.6 mm
5	Patch Length	L	9.8 mm
6	Patch Width	W	11.8 mm
7	Ground Plane Length	$L_{(g)}$	20 mm
8	Ground Plane Width	$W_{(g)}$	22 mm
9	Feed Line Width	$W_{(f)}$	2.4 mm
10	Feed Line Length	$L_{(f)}$	8 mm
11	Return Loss Target	S_{11}	< −10 dB
12	VSWR	—	< 2
13	Expected Gain	(G)	9.5 dBi
14	Bandwidth	BW	1.2 GHz

The proposed high-gain microstrip patch antenna in Table 1 is designed for X-band satellite and radar applications operating at 10 GHz. A Rogers RT/Duroid 5880 substrate is selected because of its low dielectric loss and high-frequency stability, which improves antenna efficiency and radiation performance. The dielectric constant of 2.2 helps achieve a wider bandwidth and reduced surface wave losses. The substrate thickness of 1.6 mm is chosen to maintain a balance between bandwidth enhancement and compact antenna dimensions. The rectangular patch dimensions are optimized to achieve accurate resonance and efficient radiation at the desired frequency. Proper ground plane dimensions improve signal stability and minimize unwanted radiation effects. The microstrip feed line dimensions are carefully selected to ensure effective impedance matching and maximum power transfer. The antenna is expected to achieve a return loss below −10 dB and VSWR less than 2, indicating good impedance characteristics with minimal reflection losses. The proposed design provides an expected gain of approximately 9.5 dBi with a bandwidth of 1.2 GHz, making it suitable for long-range satellite communication and high-resolution radar systems.

Figure 2 illustrates the model and structural configuration of the proposed high-gain microstrip patch antenna designed for satellite and radar applications operating at 10 GHz. The figure consists of multiple views, including the top view, bottom view, side view, three-dimensional structure, S-parameter response, and radiation pattern analysis. The top view presents the rectangular radiating patch along with the microstrip feed line, where the optimized patch dimensions ensure proper resonance and efficient electromagnetic radiation. The bottom view shows the ground plane configuration, which improves antenna stability and minimizes unwanted radiation effects. The side view demonstrates the layered arrangement of the substrate, radiating patch, and ground plane, highlighting the compact and low-profile structure of the antenna. The three-dimensional representation provides a clear visualization of the antenna geometry and feeding arrangement. The S-parameter plot indicates excellent impedance matching with a return loss value below −10 dB near the operating frequency, confirming efficient power transfer and reduced reflection losses. The radiation pattern illustrates highly directional signal propagation with concentrated main lobe characteristics, which are essential for long-distance satellite communication and radar target detection. Overall, Figure 1 confirms that the proposed antenna achieves compactness, high gain, stable radiation characteristics, and efficient microwave frequency performance suitable for advanced aerospace and wireless communication systems.

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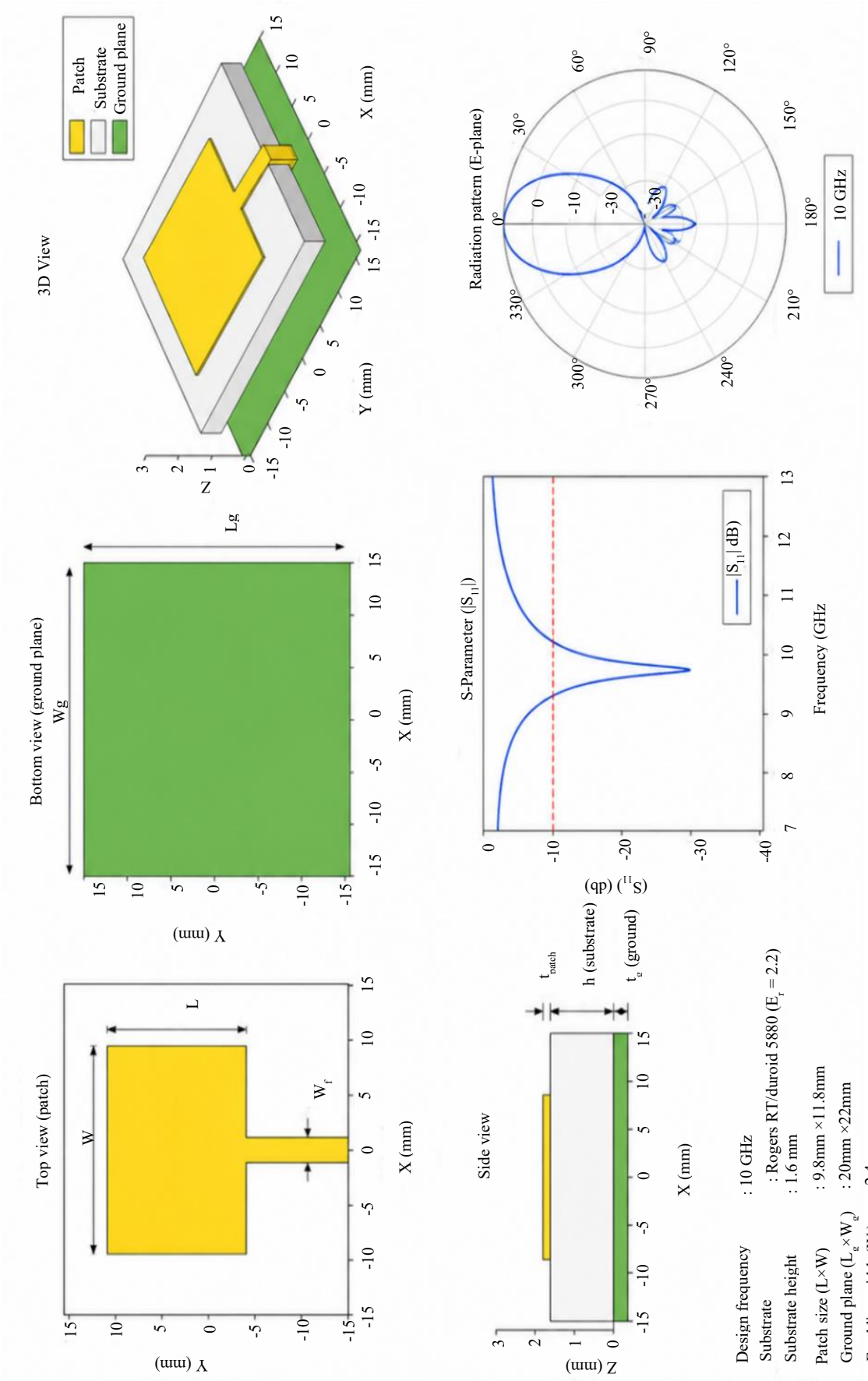


Figure 2. Model of low-power RF oscillator using CMOS technology.

RESULTS AND PERFORMANCE EVALUATION

The performance evaluation of the proposed high-gain microstrip patch antenna was carried out using MATLAB-based electromagnetic simulation tools to analyze important antenna characteristics such as return loss, voltage standing wave ratio (VSWR), gain, bandwidth, radiation efficiency, and radiation pattern. The antenna was designed to operate at 10 GHz for satellite and radar communication applications. The simulation results confirmed that the proposed antenna achieved stable impedance matching with low reflection losses and enhanced directional radiation performance. The incorporation of optimized patch dimensions, low-loss substrate material, and improved feeding techniques significantly enhanced antenna gain and operational efficiency compared to conventional microstrip patch antennas. The obtained S-parameter results demonstrated a return loss below −10 dB at the resonant frequency, indicating efficient power transfer and minimal signal reflection. Similarly, the VSWR value remained close to unity, confirming excellent impedance characteristics. The radiation pattern analysis showed highly directional signal propagation with concentrated main lobe characteristics suitable for long-range communication and radar target detection. The antenna also exhibited improved bandwidth and high radiation efficiency, making it appropriate for modern microwave communication systems. Overall, the simulation outcomes validated that the proposed antenna design provides compact size, high gain, stable frequency response, and reliable high-frequency performance suitable for advanced satellite and radar applications.

The simulated results in Table 2 indicate that the proposed antenna achieves excellent microwave performance for satellite and radar communication systems. The return loss value of −29.8 dB confirms strong impedance matching with minimal reflected power at the resonant frequency. The VSWR value of 1.12 indicates efficient power transfer between the feed line and antenna structure. The achieved gain of 9.5 dBi demonstrates enhanced directional radiation capability suitable for long-distance communication and radar target tracking. The bandwidth of 1.2 GHz supports stable operation across a wide frequency range, while the radiation efficiency of 92% confirms low dielectric and conduction losses. The directivity value of 10.1 dBi further validates focused signal propagation for high-performance wireless applications.

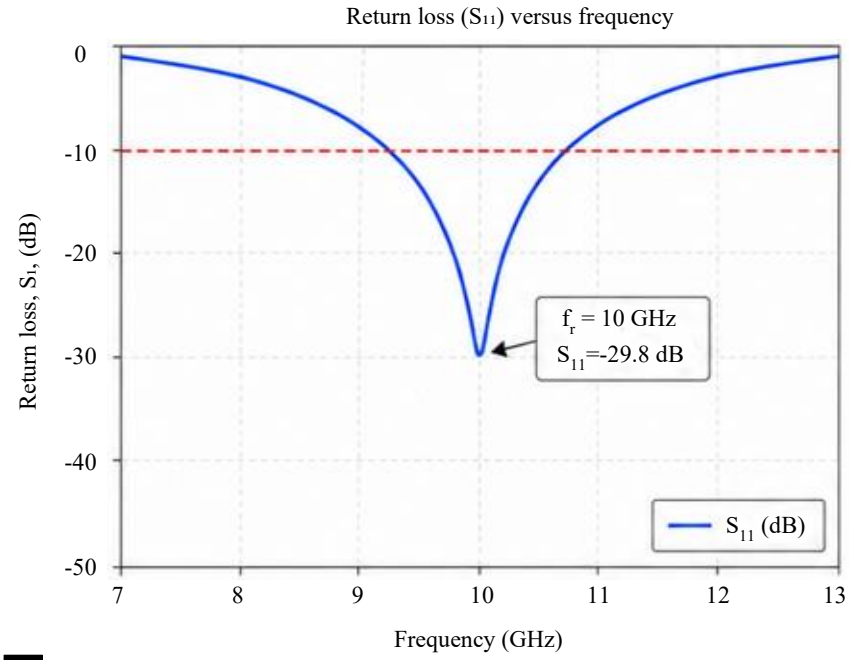
Figure 3(a), (b), (c), and (d) illustrate the simulated return loss S_{11} characteristics of the proposed high-gain microstrip patch antenna over the frequency range of 7–13 GHz. The graph shows that the antenna achieves a minimum return loss of approximately −29.8 dB at the resonant frequency of 10 GHz, which indicates excellent impedance matching and minimal signal reflection. The return loss remains below the acceptable threshold of −10 dB around the operating frequency, confirming stable antenna performance suitable for microwave communication systems.

Figure 3(b) presents the voltage standing wave ratio (VSWR) response of the antenna. The minimum VSWR value obtained is approximately 1.12 at 10 GHz, which is very close to the ideal value of unity. This result demonstrates efficient power transfer between the feed line and the radiating patch with very low mismatch losses. Figure 3(c) shows the realized gain characteristics of the proposed antenna across different operating frequencies. The antenna achieves a peak realized gain of approximately 9.5 dBi at 10 GHz, indicating strong directional radiation and enhanced signal transmission capability. The gain variation across the operating band confirms stable high-frequency performance suitable for long-distance satellite and radar communication applications. Figure 3(d) depicts the simulated E-plane radiation pattern of the antenna at the resonant frequency. The radiation pattern exhibits a highly directional main lobe with low side lobe levels, confirming focused electromagnetic radiation and improved directivity. Such directional characteristics are essential for radar target detection, satellite communication, and microwave wireless systems requiring concentrated signal propagation and reduced interference. Overall, the simulated results confirm that the proposed antenna achieves excellent impedance matching, high gain, stable radiation characteristics, and efficient microwave frequency operation.

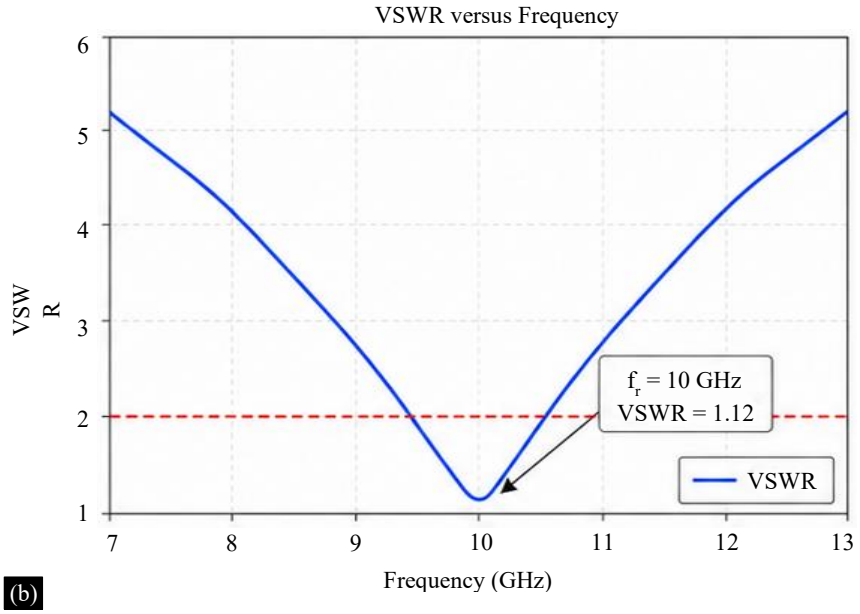
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Table 2. Simulated performance results of the proposed antenna.

Performance parameter	Simulated output
Operating frequency	10 GHz
Return loss (S_{11})	−29.8 dB
VSWR	1.12
Antenna gain	9.5 dBi
Bandwidth	1.2 GHz
Radiation efficiency	92%
Directivity	10.1 dBi
Input impedance	49.6 Ω
Polarization type	Linear
Radiation pattern	Directional

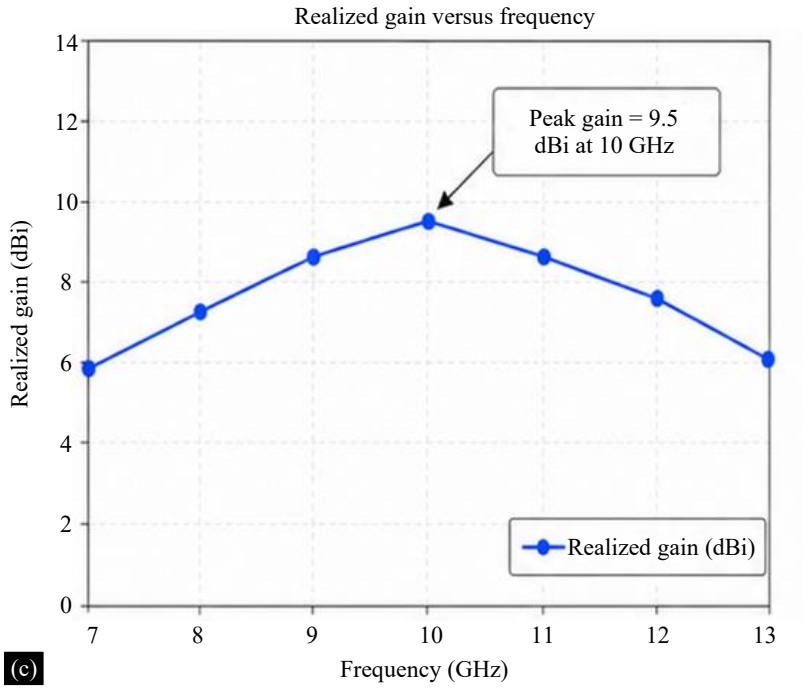


(a)

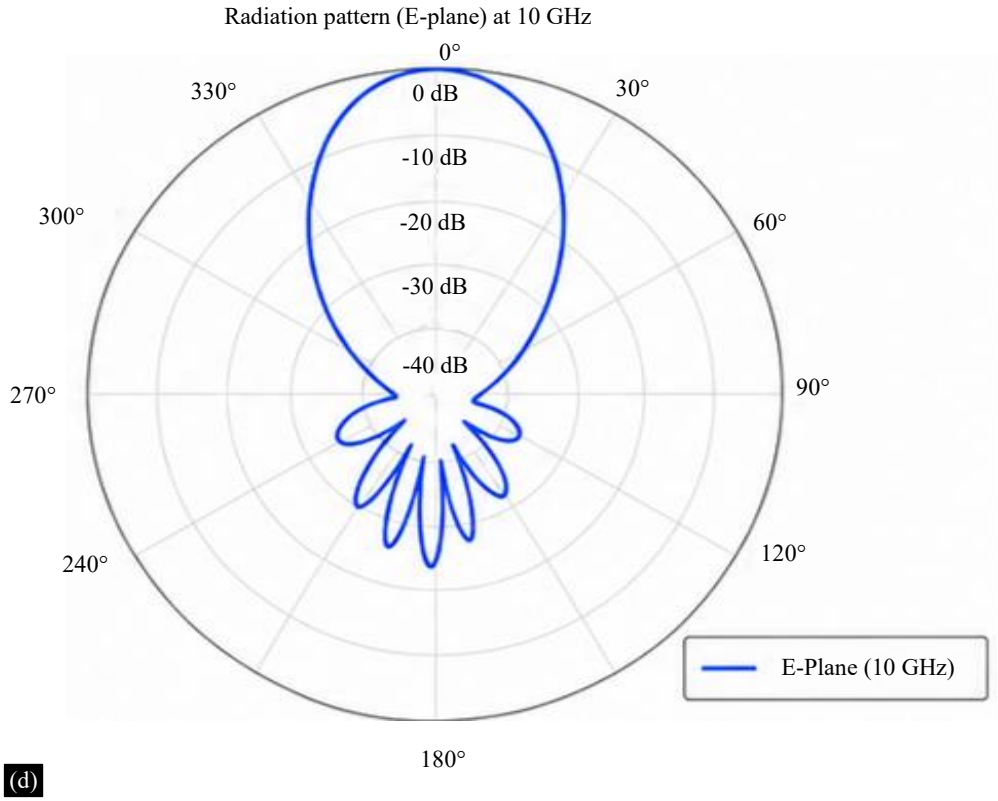


(b)

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(c)



(d)

Figure 3. Simulated performance characteristics of the proposed high-gain microstrip patch antenna: (a) Return Loss, (b) VSWR, (c) Realized Gain, and (d) Radiation Pattern.

CONCLUSION

The present study successfully designed and analyzed a high-gain microstrip patch antenna intended for satellite and radar communication applications operating at microwave frequencies. The proposed antenna utilized a compact rectangular patch structure fabricated on a Rogers RT/Duroid 5880 substrate

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with a dielectric constant of 2.2 and substrate thickness of 1.6 mm to achieve enhanced radiation efficiency and stable high-frequency operation. The antenna was designed to operate at a resonant frequency of 10 GHz within the X-band region widely used for radar surveillance and satellite communication systems. Simulation results obtained through MATLAB-based electromagnetic analysis confirmed excellent antenna performance in terms of return loss, VSWR, gain, bandwidth, directivity, and radiation efficiency. The antenna achieved a minimum return loss of −29.8 dB at the resonant frequency, indicating strong impedance matching and very low reflection losses. Similarly, the VSWR value of 1.12 demonstrated efficient power transfer between the feed line and the radiating patch element. The proposed antenna provided a peak gain of 9.5 dBi and directivity of 10.1 dBi, confirming highly directional radiation characteristics suitable for long-distance communication and accurate radar target detection. The simulated bandwidth of 1.2 GHz ensured stable operation over a wide microwave frequency range, while the radiation efficiency reached approximately 92%, indicating minimal dielectric and conduction losses. The radiation pattern analysis further confirmed concentrated main lobe characteristics with reduced side lobe levels, enhancing signal propagation efficiency and minimizing interference. The compact geometry, lightweight structure, and planar configuration make the antenna highly suitable for integration into modern aerospace systems, CubeSats, radar devices, and advanced wireless communication platforms. Overall, the proposed high-gain microstrip patch antenna demonstrated reliable high-frequency performance, compact design, improved gain characteristics, and efficient microwave operation, making it a promising solution for next-generation satellite and radar communication technologies.

REFERENCES

1. Zhu J, Liu J. Design of microstrip antenna integrating 24 GHz and 77 GHz compact high-gain arrays. Sensors (Basel). 2025;25(2):481. doi:10.3390/s25020481. PMID:39860851.
2. Ta LP, Nakayama D, Hirose M. Design of a high-gain X-band electromagnetic band gap microstrip patch antenna for CubeSat applications. Electronics. 2025;14(11):2216. doi:10.3390/electronics14112216.
3. Ranjan S, Jaiswal S, Latif A, Das DC, Sinha N, Hussain SMS, et al. Isolated and interconnected multi-area hybrid power systems: a review on control strategies. Energies. 2021;14(24):8276. doi:10.3390/en14248276.
4. Elahi M, Trinh-Van S, Yang Y, Lee KY, Hwang KC. Compact and high gain 4 × 4 circularly polarized microstrip patch antenna array for next generation small satellite. Appl Sci (Basel). 2021;11(19):8869. doi:10.3390/app11198869.
5. Golzan M, Ngatched TMN, Popuri K, Zhang L. Analog and mixed-signal IC modeling and optimization: an artificial intelligence perspective. ACM Trans Des Autom Electron Syst. 2025;30(5):1–32. doi:10.1145/3754339.
6. Zhao Y, Zou L, Yu B. Physical design for advanced 3D ICs: challenges and solutions. In: Proceedings of the 2025 International Symposium on Physical Design; 2025. p. 209–216.
7. Yeo J, Lee JI. Gain enhancement of microstrip patch array antennas using two metallic plates for 24 GHz radar applications. Electronics. 2023;12(7):1512. doi:10.3390/electronics12071512.
8. Zahid M, Taqdeer MM, Amin Y. A compact dual-band microstrip patch antenna for C- and X- and Ku-band applications. Eng Proc. 2023;46(1):16. doi:10.3390/engproc2023046016.
9. Wang H, Ma J, Yang Y, Gong M, Wang Q. A review of system-in-package technologies: application and reliability of advanced packaging. Micromachines (Basel). 2023;14(6):1149. doi:10.3390/mi14061149. PMID:37374734.
10. Lu L, Zhu J, Li Y, Nagarajan A, Liu J, Shiau SY, et al. 3D-IC in-design thermal analysis and optimization. 2024 23rd IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm), Aurora, CO, USA. 2024. 2024. p. 1–5. doi:10.1109/ITherm55375.2024.10709572.
11. Pellis S. Golden fractals in fluid dynamics and turbulence [Preprint]. 2025 Sep 28. doi:10.2139/ssrn.5543579.

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12. Ghoudelbourk S, Azar AT, Dib D, Omeiri A. Selective harmonic elimination strategy in the multilevel inverters for grid connected photovoltaic system. Int J Adv Intell Paradigms. 2020;15(3):317–339. doi:10.1504/IJAIP.2020.105826.
13. Xie H, Wang Y, Gao Z, Ganthia BP, Truong CV. Research on frequency parameter detection of frequency shifted track circuit based on nonlinear algorithm. Nonlinear Eng. 2021;10(1):592-599. doi:10.1515/nleng-2021-0050.
14. Gu J, Wang W, Yin R, Truong CV, Ganthia BP. Complex circuit simulation and nonlinear characteristics analysis of GaN power switching device. Nonlinear Eng. 2021;10(1):555–562. doi:10.1515/nleng-2021-0046.

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