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ORIGINAL

Design and Analysis of a Microstrip Antenna for Superior 5G Communication Performance

Diseño y análisis de una antena microstrip para mejorar las prestaciones de las comunicaciones 5G

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ABSTRACT

The continuous advancement in communication systems is propelled by the growing demand for fifth-generation (5G) technology, aiming to meet the growing demands of systems that are small in size, operate at high speeds, and have a wide bandwidth. In order to address these requirements, innovative and highly efficient antenna configurations are of paramount importance. This article introduces a microstrip antenna that has been meticulously designed for optimal performance 5G systems. Optimized for 5G communication systems, the research focuses on the design and simulation of microstrip patch antennas which is shaped like butterfly, resonating at a frequency of 50,5 GHz. A Rogers RT5880 (lossy) substrate with a dielectric constant of 2,2 was employed in the antenna design. The dimensions of the proposed antennas were 6 × 6,5 × 0,787 mm^3, which resulted in a geometric configuration resembling a butterfly. A comprehensive performance assessment involves exhaustive simulations using the CST Studio Suite application suite. In order to optimize critical parameters such as the Voltage Standing Wave Ratio (VSWR), reflected power, gain, frequency range (BW), and radiation pattern, the dimensions were meticulously adjusted. Significantly, the antenna operating at 50,5 GHz demonstrated a gain of 6,8 dB, in addition to a broad bandwidth of 5,364 GHz and an outstanding VSWR of 1,0131. The outcomes successfully underscore the outstanding performance exhibited by the butterfly-shaped design, thereby establishing its suitability for implementation in 5G networks.

Keywords: Microstrip Antenna; Rogers RT5880; 5G Antenna; CST Software; 50,5GHz.

RESUMEN

El continuo avance de los sistemas de comunicación se ve impulsado por la creciente demanda de tecnología de quinta generación (5G), cuyo objetivo es satisfacer las crecientes exigencias de sistemas de pequeño tamaño, que funcionen a alta velocidad y tengan un amplio ancho de banda. Para hacer frente a estos requisitos, las configuraciones de antena innovadoras y altamente eficientes son de vital importancia. Este artículo presenta una antena microstrip que ha sido meticulosamente diseñada para sistemas 5G de rendimiento óptimo. Optimizada para sistemas de comunicación 5G, la investigación se centra en el diseño y simulación de antenas de parche microstrip con forma de mariposa, que resuenan a una frecuencia de 50,5 GHz. En el diseño de la antena se empleó un sustrato Rogers RT5880 (con pérdidas) con una constante dieléctrica de 2,2. Las dimensiones de las antenas propuestas fueron 6 × 6,5 × 0,787 mm^3, lo que dio lugar a una configuración geométrica parecida a una mariposa. Una evaluación exhaustiva del rendimiento implica la realización de simulaciones exhaustivas utilizando la suite de aplicaciones CST Studio Suite.

Para optimizar parámetros críticos como la relación de onda estacionaria en tensión (VSWR), la potencia reflejada, la ganancia, el rango de frecuencias (BW) y el diagrama de radiación, se ajustaron meticulosamente las dimensiones. En concreto, la antena que funciona a 50,5 GHz demostró una ganancia de 6,8 dB, además de un amplio ancho de banda de 5,364 GHz y una extraordinaria VSWR de 1,0131. Los resultados obtenidos ponen de manifiesto las excelentes prestaciones del diseño en forma de mariposa, que lo hacen idóneo para su implementación en redes 5G.

Palabras clave: Antena Microstrip; Rogers RT5880; Antena 5G; Software CST; 50,5GHz.

INTRODUCTION

The progression towards fifth generation (5G) communication systems is motivated by the growing demand for networks that are compact, fast, and have a broad bandwidth. Presently, mm-wave communication technology is the subject of investigation by telecommunications researchers who aim to improve system performance and attain high data transmission rates.[1] The principal applications of radio resources in 4G networks are mobile application usage and video downloads.[2] On the contrary, the need for enhanced functionality and assistance for numerous operators and consumers has propelled the creation of 5G telecommunications, an innovative technological advancement designed to cater to a wide array of requirements across sectors including energy, healthcare, media, industry, and transportation. The main focus of the fifth generation (5G) technology is to provide low latency, energy conservation, and the provision of high-quality services in every location. Millimeter bands, enormous IoT (MIMO), and ultra-dense networks are fundamental technologies in 5G.[3,4,5,6,7,8] Significant advancements in 5G technology center around the enhancement of energy efficiency, the reduction of response times to 1–5 milliseconds, the acceleration of data transmission (10 GB/s, ten times quicker than 4G), and the improvement of network capillarity.[9] Increased network capacity and performance have resulted from the implementation of the millimeter-wave band, which operates between 30 GHz and 300 GHz.[10] Nonetheless, mm-waves present obstacles including atmospheric disruptions, attenuations along the propagation path, and increased manufacturing expenses.[11] The 28 GHz millimeter-wave frequency band is particularly advantageous in terms of mitigating data transfer losses.[12] Patch or printed antennas are extensively required for 5G implementations due to the economical design, and compactness that ease the integration with wide range of devices, including spacecraft, aircraft, satellites, missiles, automobiles, military equipment, and so on.[13,14] The design of a butterfly microstrip patch antenna for 5G wireless communication technology is detailed in this paper. Enhancing antenna efficiency and surpassing dimension restrictions are the major aims of this design. The antenna functions at a resonant frequency of 50,5 GHz and possesses a diminutive profile, measuring 6 mm × 6,5 mm × 0,787 mm. Practical introductions that provide context and background for the development of the antenna are included in the paper. Furthermore, it provides an exhaustive account of the antenna design procedure, including a discussion of the methodology and factors that were considered throughout the design phase. The proposed antenna is designed and simulated using the Computer Simulation Technology (CST) software package. The simulation is focued on the evaluation of the behavior, characteristics, and performance of the antenna. After analyzing and comparing the simulation results with those of existing antennas, the effectiveness and efficiency of the proposed design are determined. Finally, the paper provides a summary of the results obtained, possible areas for development, and an evaluation of the proposed antenna's suitability for 5G wireless communication applications.

Antenna Design

The prototype of the antenna is illustrated figure 1, featuring a microstrip patch in the distinctive form of a butterfly as the radiating element located on the topmost layer of a substrate. The antenna structure comprises of three discernible layers, the uppermost layer incorporates the butterfly-shaped patch, the middle layer incorporates a 0,787 mm-thick Rogers RT5880 (Lossy) substrate with a relative permittivity (εr) of 2,2, and the lowermost layer functions as the ground plane. Both the upper and lower layers are composed of 0,035 mm-thick copper materials, which contribute considerably to the enhanced radiative performance of the antenna. The configuration of the antenna enables it to operate with optimal efficiency at the intended frequency while displaying the desired attributes of radiation. In order to optimize the design for its designated purpose, exceptional performance has been achieved. The primary design of the proposed antenna was designed using CST microwave studio. The antenna was designed depending on the equations (1), (2), (3), (4), (5) and the parametric study on the antenna. The primary design of the antenna was optimized for operation at a frequency of 60,6 GHz with a bandwidth of 2 GHz. The gain achieved for this primary design reached 2 dB.

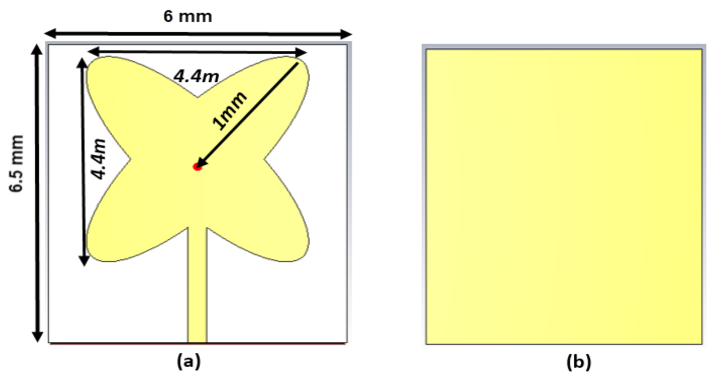

Figure 1. Initial Design of Proposed Microstrip Patch Antenna (a) Front View (b) Back View

The microstrip antenna design involved the utilization of the following equations.(15,16)
The width of the patch was found by:

$$W_p = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad (1)$$

Where Wp Is the patch width. C Represents the speed of light in a vacuum. fr Represents the frequency in GHz (Gigahertz). ε_r represents the dielectric constant of the material used for the patch.
The height of the patch was found by:

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

$$\Delta L = 0.412(h)\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)} \qquad (3)$$

Where L Is the patch height. ε_{eff} is an effective dielectric constant.
The effective dielectric constant (ε_{eff}) of the microstrip antenna can be calculated using the following equation.

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\ \frac{1}{\sqrt{1+12\left(\frac{W}{h}\right)}} \qquad (4)$$

Half-diameter (R) of the modified butterfly-shaped microstrip patch antenna can be obtained using the following equation.

$$R = \frac{8.79\times10^9}{f_r\sqrt{\varepsilon_r}} \qquad (5)$$

In order improve the antenna performance, some modifications were applied on the patch including using the slits technique. The effect of changing the patch is shown in figure 2. This paper introduces a modified butterfly-shaped microstrip patch antenna that has been updated to include the essential modifications required to attain the intended target frequency for 5G wireless applications. At the prescribed frequency, enhancing the efficacy of the antenna and attaining the intended radiation characteristics were of particular importance. In order to optimize the operational capabilities of the initial antenna, a vertical slits were incorporated into the patch, which constitutes the topmost layer of the antenna to reduce the operating frequency and to improve antenna gain and bandwidth. By strategically augmenting the electromagnetic signal, it was capable of being precisely calibrated to the intended target frequency. Through the implementation of these substantial alterations, the antenna successfully achieved the targeted return loss of -43,8 dB at a frequency of 50,5 GHz, demonstrating a bandwidth of 5,4 GHz. Simultaneously, the gain was elevated to 6,8 dB, showcasing enhanced performance in these key parameters. The desired results were achieved with the incorporation of the slits, which transformed the initial antenna into an ideal and highly efficient design for 5G applications. The critical measurements and values for different antenna components are presented in table 1. These include the substrate height (hs), copper thickness (t), ground width (Wg), and ground length (Lg), in addition to antenna patch width (Wp) and length (Lp). The aforementioned values are crucial in guaranteeing the efficiency and overall performance of the antenna in the context of 5G wireless applications.

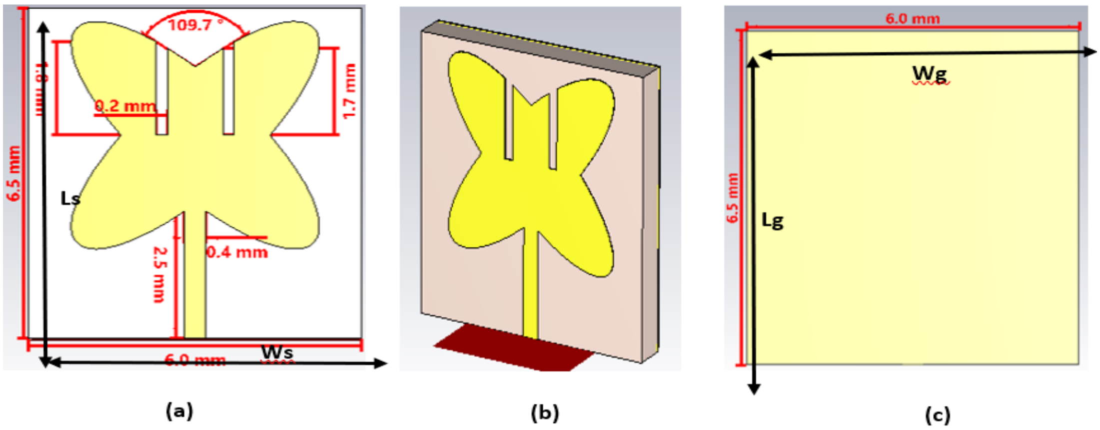

Figure 2. Geometry of the Improved Proposed Antenna (a) Patch Layer, (b) 3D view of the proposed antenna (c) Ground Layer

Table 1. Antenna Measurements and Component Parameters

Component	Notation	Value
Ground Width= Substrate Width	Wg= Ws	6 mm
Ground Length= Substrate Length	Lg= Ls	6,5 mm
Antenna Patch Width	Wp	4,4 mm
Antenna Patch Length	Lp	4,4 mm
Substrate Height	hs	0,787 mm
Copper thickness	t	0,035 mm
Central Frequency	fr	50,5 GHz
Relative permittivity	ε_r	2,2

RESULTS AND DISCUSSION

All the simulation results of the proposed antenna were in the regulated and accepted ranges for 5G application. The assessed parameters include the Voltage Standing Wave Ratio, Return loss, Bandwidth, Radiation pattern, and the antenna's efficiency.

Return loss

The simulation results indicate that the designed antenna accurately meets the desired parameter of a return loss of -10 dB, which is regarded as optimal for mobile or wireless technology. The antenna is specifically tuned to operate at a frequency of 50,5 GHz, as shown in figure 3. The measured return loss at this frequency is -43,8 dB, indicating the reflected power experiences a substantial decrease. The outstanding performance of the antenna is validated by the S_{11} parameter, which denotes the return loss, which has a value of -43,8dB at the intended -10 dB level. The antenna's favorable return loss value renders it a robust contender for 5G implementations, as it guarantees effective power transmission with limited signal attenuation.

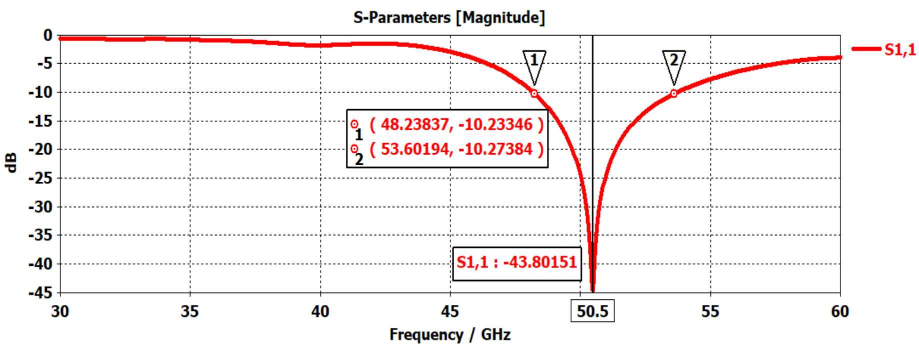

Figure 3. Frequency versus Return Loss in the simulation results

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Bandwidth

The antenna's bandwidth, denoted as 5,364 GHz in figure 3, spans a frequency range of 48,238 GHz to 53,602 GHz. The aforementioned frequency range is highly suitable for 5G applications, which necessitate a broad spectrum to facilitate swift and effective wireless communication.

Voltage Standing Wave Ratio (VSWR)

The VSWR, which denotes the impedance compatibility between the antenna and transmission line, is a critical parameter. An improved performance is denoted by a lower VSWR value, which signifies a more precise alignment between the antenna and the transmission line. The VSWR value is determined to be 1,0131 in figure 4, which is exceptionally near the optimal value of 1. This implies that the antenna demonstrates exceptional impedance matching capabilities and effectively transmits power.

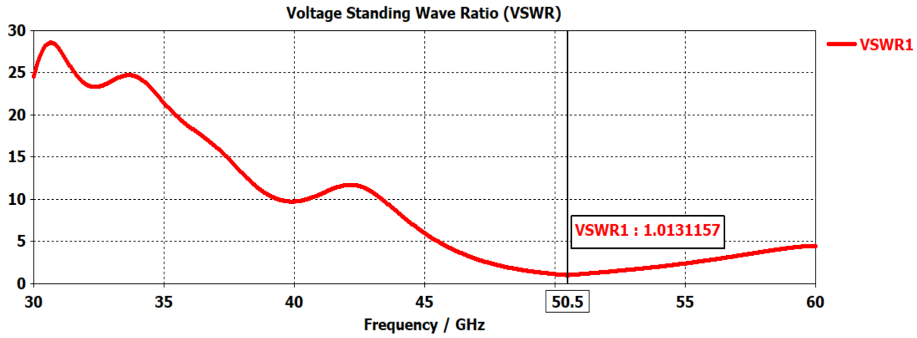

Figure 4. VSWR Variation with Frequency

In figure 5, a polar plot is presented, illustrating the antenna efficiencies. The plot indicates that the antenna's efficiency is 67 %. This value suggests that the antenna is performing very well in converting the input power into radiated power, with 67 % of the input power effectively being radiated as electromagnetic waves. A higher efficiency value indicates a more effective antenna system, making it highly suitable for various communication applications where efficient radiation is crucial for achieving optimal performance.

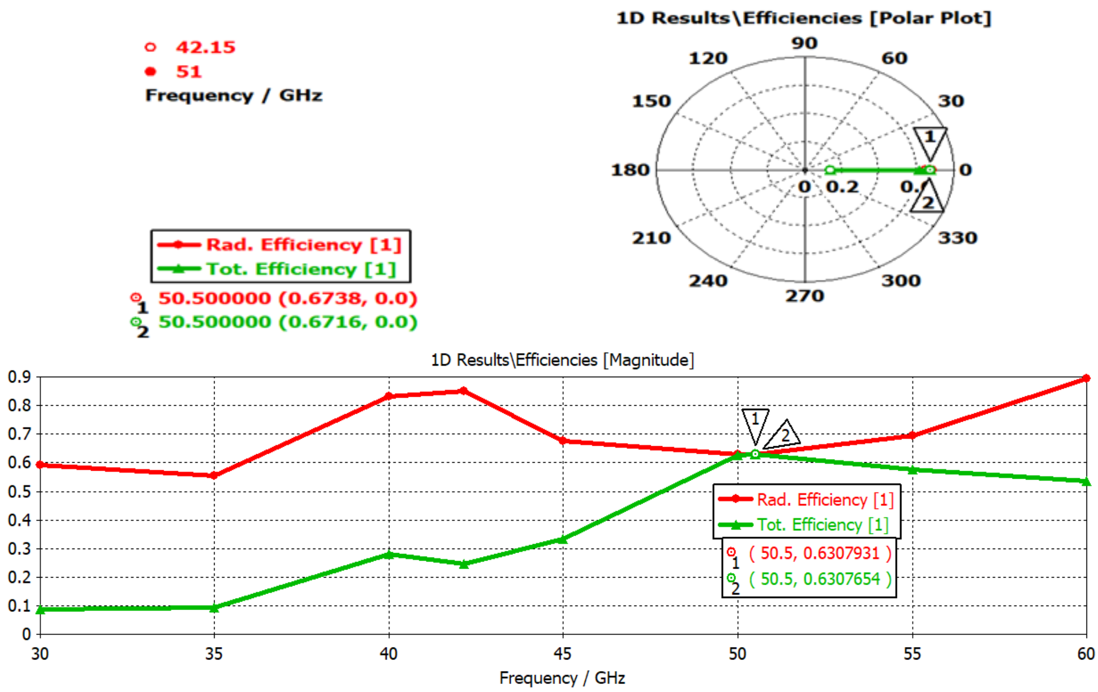

Figure 5. Displays the polar plot of antenna efficiencies

Radiation and Surface Current

The analysis of an antenna's radiation pattern yields significant information regarding its operational efficiency and coverage attributes. The three-dimensional radiation pattern of the proposed antenna is depicted in figure 6. The antenna exhibits a gain of 6,8 dB, which signifies its capability to efficiently

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concentrate and emit electromagnetic energy in the intended direction. The 67 % radiation efficiency indicates the effectiveness of the antenna in transforming electrical energy into radiated energy. figure 7 presents supplementary information pertaining to the radiation pattern. Upon observation, the main lobe direction is determined to be 29,0 degrees, signifying the orientation in which the antenna emits its maximum power. The angular width (3 dB) serves as a measurement of the main lobe's extent, which is 93,0 degrees. The side-lobe level, represented by -1,5, indicates the intensity of the radiation directed in a direction opposite to that of the primary lobe. The effectiveness of the microstrip patch antenna for 5G technology is underscored by the aforementioned radiation pattern characteristics, which include directional radiation, a substantial gain, and a reasonable radiation efficiency.

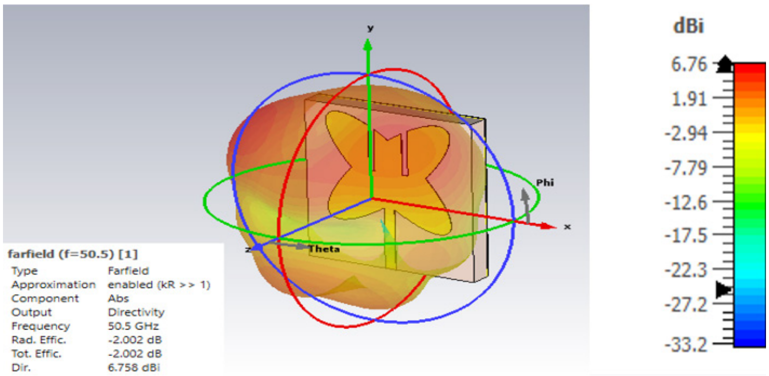

Figure 6. Showcases the 3D directivity pattern of the proposed antenna

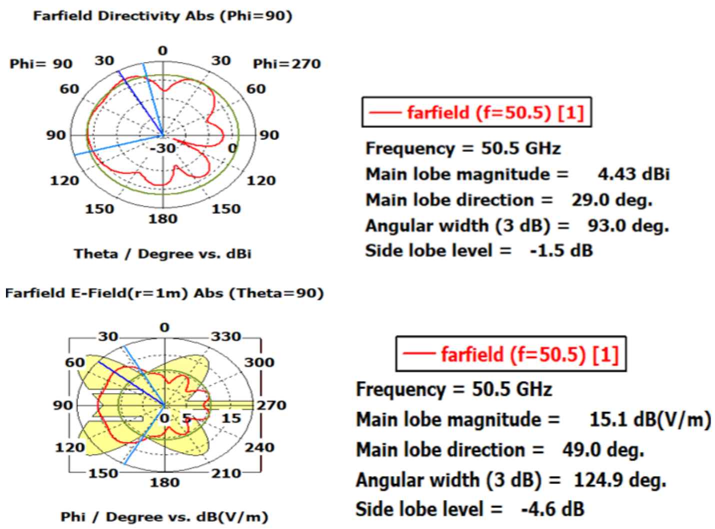

Figure 7. Illustrates the 2D directivity pattern of the proposed antenna in Theta and Phi

The distribution of the surface current of the proposed antenna is shown in figure 8.

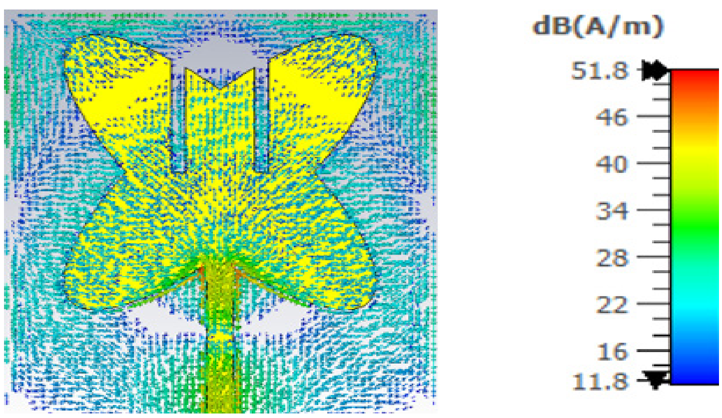

Figure 8. The distribution of surface currents at 50,5 GHz

Comparison with Other Antennas in 5G Applications

The performance of the proposed antenna is remarkable and differentiated from that of the antennas listed in table 2. It succeeds in a number of critical domains. To begin with, it encompasses a wider coverage area and provides superior signal intensity due to its high gain factor. Additionally, it possesses a minimal power loss and a high efficiency of signal transmission due to its low reflection coefficient. Furthermore, it offers an extensive frequency range that is well-suited for 5G applications, facilitating the swift and effective transfer of substantial volumes of data. Furthermore, the diminutive dimensions of the proposed antenna render it exceptionally well-suited for seamless integration into mobile devices and embedded systems. The compact size of this component improves the adaptability of device design and enables smooth incorporation of the antenna into 5G applications. In brief, the exceptional performance exhibited by the proposed antenna renders it a highly suitable option for augmenting wireless communications and maximizing the efficacy of 5G applications. The butterfly antenna, by virtue of its groundbreaking design and outstanding performance, stands as a notable resolution for fulfilling the requirements of contemporary communications and augmenting the user experience within the realm of wireless communications.

Table 2. Comparison of Proposed Antenna with Existing Antennas

Antenna	Size)mm^3)	Central Frequency (GHz)	S_{11} (dB)	Gain (dB)
Ant(17)	6,2 × 8,4	28	-22,5	5,06
Ant(118)	7 × 7	28	-27,79	6,59
Ant(19)	6,1×11	38	-24,35	5
Ant(20)	39,3 ×30,65	28	-46,1	6,61
Ant(21)	10 × 10	28	-35,73	5,54
Ant(22)	11 × 8	28	-21	2,6
Ant(23)	7 × 3	28	Below -10	3,75
Ant(24)	6×6,12	39,23	-35	7,5
Proposed	6×6,5	50,5	-43,8	6,8

CONCLUSIONS

The principal objective of the presented research is the creation of a compact butterfly-shaped microstrip patch antenna that demonstrates effectiveness in achieving high gain at the resonant frequency of 50,5 GHz. The research outcomes reveal that the antenna exhibits notable characteristics, including a gain of 6,8, a return loss of -43,8 dB, a bandwidth of 5,364 GHz, and a VSWR of 1,0131. These findings strongly indicate the suitability of the developed antenna for 5G applications. To further enhance its capabilities, potential modifications, such as circular and ring-type array adjustments, could be explored. Future investigations might delve into alternative methodologies and materials to attain even superior performance. The simulation results underscore the proposed antenna's potential for wireless communication systems, and subsequent empirical investigations can be pursued to validate the outcomes derived from simulation.

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All authors reviewed the results, approved the final version of the manuscript and agreed to publish it.

AUTHORSHIP CONTRIBUTION

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