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REGULAR ARTICLE

Performance Evaluation of Compact Microstrip Antenna Design for 5G Wireless Applications

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This research endeavor sought to explore a small (12 × 12 × 0.8) mm^3 microstrip patch antenna. This design boosts the characteristic of microwave circuits, such as narrow bandwidth, gain, reduced return loss, VSWR, also enhance the current distribution, etc. The proposed antenna is built on a Rogers RT Duroid 5880 board of 0.8 mm in thickness and exhibits a dielectric constant of ($\varepsilon_r = 2.2$). It is intended to work in the frequency range of 28 GHz to 32.5 GHz. To improve the radiation performance of the suggested antenna structure, rectangular slots with inset feed technique have been created from the radiating patch for the change of current distribution. The proposed antenna has a 4 GHz bandwidth and operating frequency range is 28 GHz to 32.5 GHz. Because of this, the suggested antenna design is compact and suitable for greater frequency ranges. The simulation outcomes demonstrate that the antenna model is accurate. Performance measurements like return loss, gain, and VSWR have improved. All necessary simulations are carried out using the EM simulator Ansys HFSS, and a comprehensive comparative study based on the present antennas is accomplished. The suggested antenna achieves high gain for the desired frequency band, has a VSWR of less than two, and has good impedance matching at $|S11| < -10$ dB. The recommended antenna can be used for 5G high-frequency applications because it resonates at millimeter wave frequencies. These outstanding outcomes indicate that the suggested antenna would be a respectable option for 5G mm-wave applications.

Keywords: Ansys HFSS, Compact size, Inset feed, Microstrip antenna, 5G applications, Slotted patch.

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1. INTRODUCTION

Recent developments in the field of wireless communication have brought about a challenge in the creation of communication system standards. 4G communication has been standardized until now, while 5G has just been confirmed in terms of the technology's maturation; it is expected to launch by 2020 [1]. Estimates suggest that the volume of traffic in 2020 will be 1000 times greater than the 2010 traffic [2]. Security, trustworthiness, low-latency connectivity, high data transfer rate, and vast capacity are the crucially important properties of 5G technology [3]. Anticipated to allot real-time wireless regulation and D2D interaction through communication, the energy utilization can be decreased up to 1000 times [4]. 5G millimeter wireless use will feature a data rate of above 100 Mbps with full mobility and over 1 Gbps with low mobility [5].

It is predicted that 5G will be a major contributor to the development of the 21st century. This is expected to be beneficial in a variety of areas including growth of the economy, educational opportunities, job creation, transportation networks, electrical infrastructure, health care systems, and industrial development [6]. Additionally, 5G technology could be integral to improving everyday activities. This technology will enable the connection of multiple digital gadgets and appliances, like thermostat systems, printers & Scanners, air conditioners, fridges, LED lighting, microwaves, and door locks. This will make it possible to use remote control to manage any of these devices. A comprehensive system with minimal restrictions, 5G will enable the world access to the Global Wireless Web (WWWW) and a dynamical, impromptu wireless network. It will also provide greater appeal and efficiency to the billing system by providing a high-definition experience in combination with bidirectional, extensive bandwidths up to gigabits and multiple pathways for data transfer [7].

Spectrum allocation is a crucial objective of 5G communications, with the millimeter Wave (mm-W) band between 20 and 60 GHz being the primary suggested frequency range [1]. Further, the 5G mobile systems have

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been recommended to utilize an additional seven bands, namely 27.5-29.5 GHz, 33.4-36 GHz, 37-40.5 GHz, 42-45 GHz, 47-50.2 GHz, 50.4-52.6 GHz, and 59.3-71 GHz [3]. Due to its lower atmospheric electromagnetic wave absorption rate than 60GHz, the operational frequency is specifically thought to be in the Ka-band (28/38 GHz) [7-8]. Patch antennas are vital for the advancement of contemporary wireless communications, including the GPS, WLAN, Wi-Fi, Mobile Communications, and Microwave Sensors etc. These antennas are frequently affordable, low profile, easy to build, and miniature in size. Additionally, their design, when implemented with the appropriate slots and allocations, produces favorable outcomes in terms of bandwidth (BW), resonant frequency (f_r), gain in dB, impedance, and return loss etc.

Different methods of connecting an antenna to its source include the Microstrip Feed Line Technique, the Coaxial Feed Technique, Aperture Coupling Feeding, and the Proximity Coupling Technique [9]. Each approach has its advantages and is driven by unique considerations when selecting. These techniques differ in terms of accessibility, cost, implementation, impedance matching, and caused radiations. Although these antennas offer benefits, they also have drawbacks due to their low strength and restricted bandwidth. Slotted patches, thick substrates with low effective permittivity, the inclusion of several resonances, and impedance optimization are a few solutions to this problem. To enhance gain limitation, an array configuration might be used [10-11].

Performance analysis of a compact microstrip antenna design specifically geared towards 5G wireless systems is essential in order for users to gain access to high-speed services. This analysis is important as 5G microstrip antennas need to be smaller in size and more efficient in performance than those of its predecessor, 4G. Several parameters must be considered in order to ensure effective design, such as radiation pattern, antenna efficiency, gain, standing wave ratio, return loss, resonance frequency, and input impedance. By studying and comparison of different design configurations, such as a meandered line microstrip antenna or an inverted-F antenna, an antenna can be created with optimal performance characteristics. The results are then used to assess the performance of the proposed antenna in terms of the radiation pattern, gain, efficiency, and other parameters. This helps to determine the suitability of the design for 5G applications.

This study is designed to develop a compact microstrip antenna with an elevated efficiency for 5G mobile communications between 28-32.5 GHz frequencies. In order to accomplish this goal, the first step is to design and analyze a conventional rectangular microstrip patch antenna with an inset feed. By cutting certain sides of a square antenna, the second antenna is shaped, and then modifications are made to add slots to an already existing rectangular microstrip antenna to increase its gain, bandwidth, and overall performance. The desired outcomes of this proposed antenna can be achieved through Ansys HFSS, software that makes it possible to simulate and analyze the performance of the antenna. With this tool, the designer can adjust parameters to meet specific objectives, transmit signals, check background noise, and more.

2. ANTENNA GEOMETRY AND DESIGN

The Final antenna dimensions are 12 mm × 12 mm × 0.8 mm for the substrate. The Roger RT Duroid 5880 substrate material, boasting a relative permittivity of 2.2, is utilized to construct the antenna. For antenna excitation, a 50 Ohm microstrip line etched on the lower layer is used. The upper layer of the antenna consists of a hexagonal patch, with two rectangular slots (which looks like a sheep face patch antenna). The basic dimensional parameters are calculated by using the numerical formulas referred in ref. [12]. The formulae produced dimensions which are listed in Table 1, and Figure 1 presents the antenna design derived from these dimensions. The information could be leveraged to improve the antenna's bandwidth and miniaturize its size.

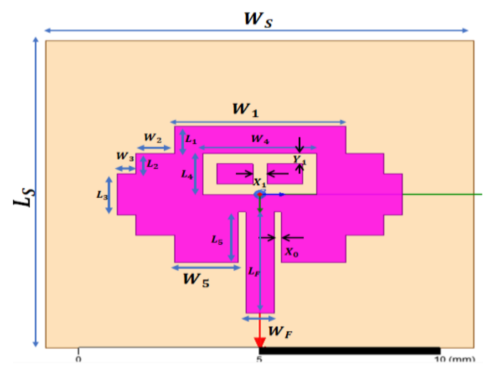

Fig. 1 – The proposed antenna model

Table 1 – The most suitable sizes for the proposed antenna measurements

Parameters	Values (mm)	Parameters	Values (mm)
W_S	12	L_2	0.8
L_S	12	W_3	0.524
H_S	0.8	L_3	1.6
W_p	6.952	W_4	3.2
L_p	5.34	L_4	0.8
W_F	0.788	W_5	1.312
L_F	3.96	L_5	1.98
W_1	3.812	X_0	0.2
L_1	1.076	X_1	0.4
W_2	1.076	Y_1	0.4

3. SIMULATED RESULTS WITH STEP WISE COMPARISON

In this investigation, a few distinct approaches to antenna design are utilized: a basic rectangular microstrip antenna (Steps 1-4) and a slotted microstrip antenna (Step 5), both simulated using Ansys HFSS software. The host substrate for this work is Roger RT Duroid 5880 (tm), having a dielectric constant of ($\varepsilon_r = 2.2$) a thickness of ($H_s = 0.8\ mm$), and a loss tangent ($\delta = 0.0009$). Operation of the antennas is targeted for the 28 GHz-32.5 GHz frequency range. Figure 2 demonstrates the step-wise variation of return loss relative to frequency. Analysis of the – 10 dB return loss reveals that the proposed antenna has a recorded return loss of – 28 dB at 31 GHz with a 4.5 GHz bandwidth spanning from 28 GHz to 32.5 GHz. Figure 3 also shows that VSWR remains below 2 at 31 GHz and extends to the range of 28 GHz to 32.5 GHz. The peak gain of the antenna is shown in Figure 4. The 2D radiation patterns for various frequencies are compared and displayed in Figure 5. The antenna shows directional patterns concentrating radiating energies along the plane of X axis for the suggested structure. To accurately understand the level of electric field strength or surface power output, it can be measured through two separate planes, the horizontal and the vertical. By doing this, a standardized representation of the focus pattern can be effectively visualized. This can be depicted in three dimensions, allowing for a more immersive experience [13-15]. The gain plots in 3D representation for different steps of the proposed antenna at 24 GHz are shown Figure 6. The gain for final stage is 6.37 dB which is good enough or better than the other previous steps of antennas. So, the proposed antenna is a better candidate for 5G high frequencies applications. The results for different design stages are summarized in Table 1.

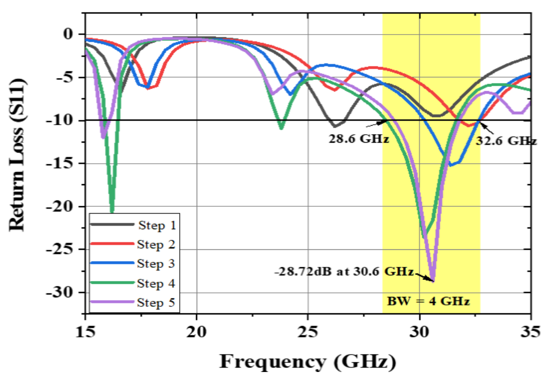

Fig. 2 – Step-wise antenna return loss vs frequency for 5G applications

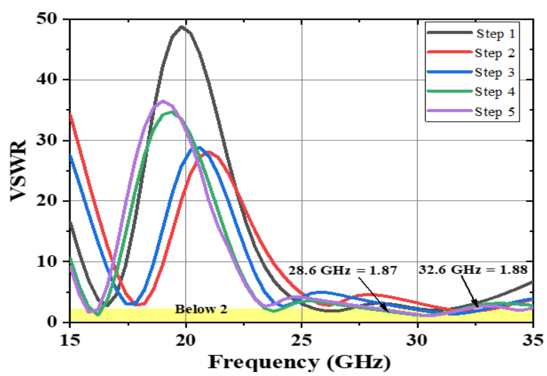

Fig. 3 – Step-wise antenna VSWR vs frequency

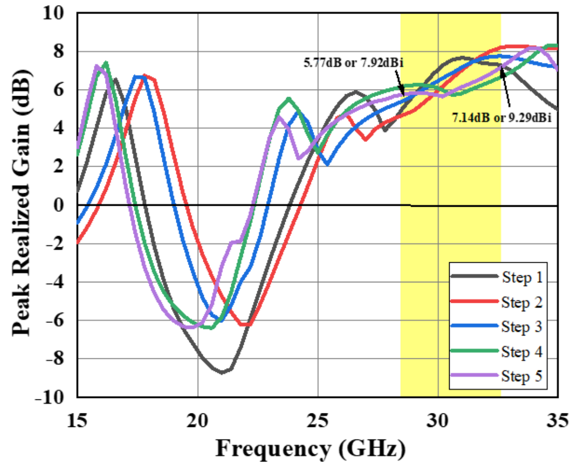

Fig. 4 – Step-wise peak realized gain vs frequency of proposed antenna

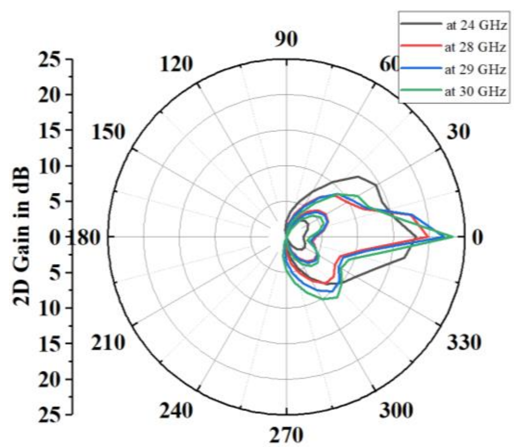

Fig. 5 – 2D Gain plot of the proposed antenna at 24 GHz, 28 GHz, 29 GHz and 30 GHz

Table 2 – Comparison of results between all steps of antenna evolution

Antenna	Frequency Range (GHz)	Band-width	S_{11} (dB)	Gain (dBi)	Radia-tion Efficien-cy (%)
Step 1	26 to 26.6	0.6	– 10.75 at 26.2 GHz	7.83	> 97
Step 2	31.8 to 32.6	0.8	– 10.62 at 32.2 GHz	10.16	> 96
Step 3	30.4 to 32.6	2.2	– 15.21 at 31.4 GHz	9.57	> 87
Step 4	15.8 to 16.4, 28.6 to 31.8	0.6, 3.2	– 20.67 at 16.2 GHz, – 22.51 at 30.2 GHz	9.55, 8.14	> 91

Final Step (Step 5)	15.5 to 15.9, 28.6 to 31.6	0.4, 3	– 12.98 at 15.8 GHz, – 28.75 at 30.2 GHz	9.39, 7.80	> 91

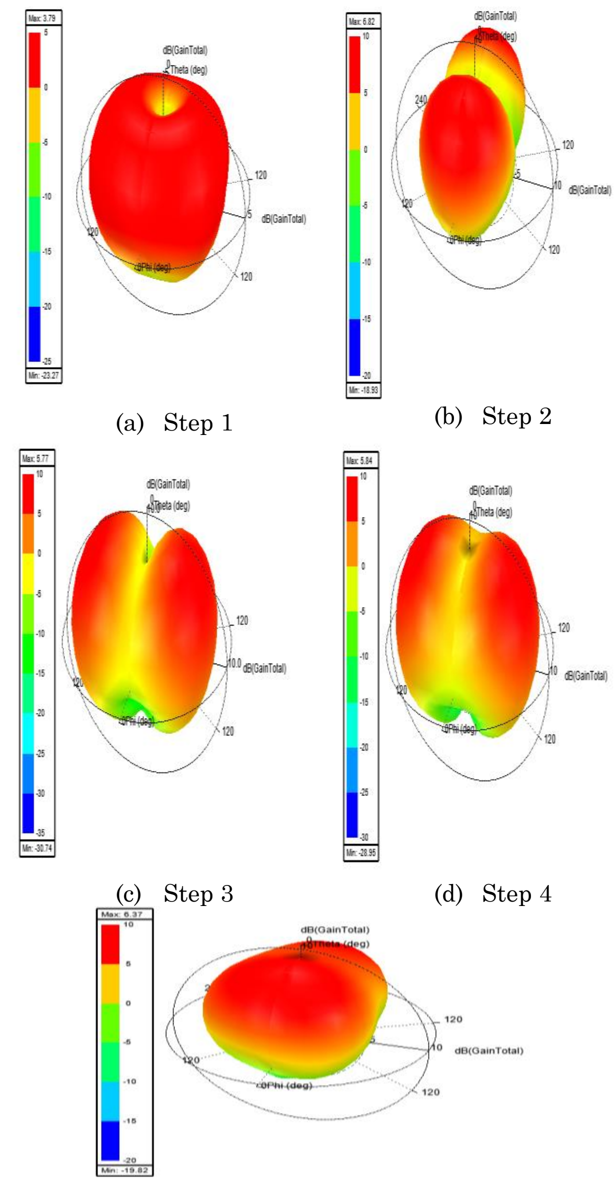

Fig. 6 – Step-wise 3D Gain plots of proposed antenna at 24 GHz

The surface current distribution of the developed antenna at a frequency of 24 GHz is presented in Figure 7. The current is concentrated around the periphery of the antenna with maximum current along the edges and minimum current at the center. The distribution is not uniform and drops off near the edges as the surface current couples to the radiation field. The highest current concentration is along the vertical edges of the patch as

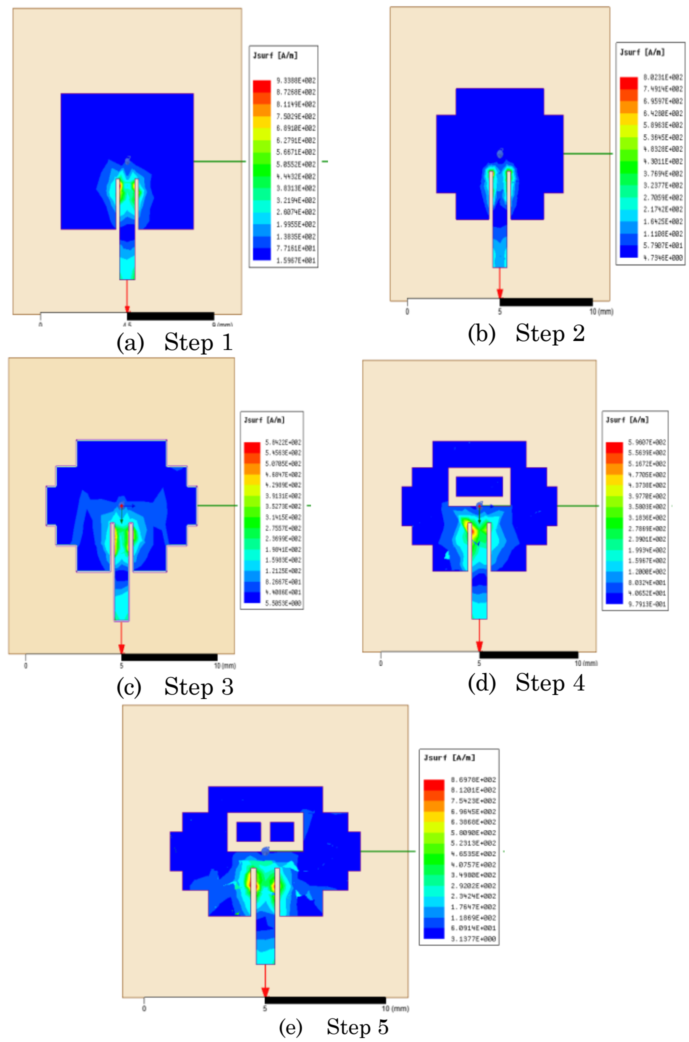

Fig. 7 – Step-wise Surface current distribution for the proposed antenna at 24 GHz

this region is usually more electrically active than the horizontal edges. With increasing frequency, the current distribution becomes more concentrated around the edges with less current present in the internal regions, leading to improved antenna performance.

4. CONCLUSION

This paper elucidates the blueprint of a minuscule, shaped-rectangular microstrip antenna intended to work at 31 GHz to enable 5G applications. The antenna's modeling was executed by using HFSS software on a Roger RT Duroid 5880 substrate that has a dielectric constant of (ε_r = 2.2) a thickness of (H_s = 0.8 mm), and a loss tangent (δ = 0.0009). The proposed antennas showed improved performance when the number of slots was varied. Adding more slots led to a decrease in the effective area but an increase in bandwidth, which is required in 5G wireless communication to boost user occupancy. The antennas are compact, measuring only 12 mm × 12 mm × 0.8 mm.

Return loss was recorded at – 28 dB and with a VSWR of 1.08, which was less than 2. The proposed step 5 offered great performance, having better gain and bandwidth characteristics. Its small size requires the antenna to be manufactured and tested with heightened accuracy to achieve the full potential of the design for 5G wireless communication. In the future, production and validation of the proposed antenna design will be possible.

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Оцінка продуктивності конструкції компактної мікросмужкової антени для бездротових додатків 5G

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У статті представлені дані дослідження невеликої (12 × 12 × 0,8) мм³ мікросмужкової антени. Її конструкція підвищує характеристики мікрохвильових ланцюгів, такі як вузька смуга пропускання, посилення, зменшені зворотні втрати, VSWR, а також покращує розподіл струму тощо. Пропонована антена побудована на платі Rogers RT Duroid 5880 товщиною 0,8 мм і має діелектрична проникність (ε_r = 2,2). Він призначений для роботи в діапазоні частот від 28 ГГц до 32,5 ГГц. Щоб покращити характеристики випромінювання запропонованої конструкції антени, прямокутні щілини з технікою вставного живлення були створені з випромінювальної ділянки для зміни розподілу струму. Пропонована антена має смугу пропускання 4 ГГц і робочий діапазон частот від 28 ГГц до 32,5 ГГц. Через це запропонована конструкція антени є компактною та підходить для більших частотних діапазонів. Результати моделювання демонструють, що модель антени є точною. Вимірювання продуктивності, такі як зворотні втрати, підсилення та VSWR, покращилися. Усе необхідне моделювання виконується з використанням електромагнітного симулятора Ansys HFSS, а також виконується комплексне порівняльне дослідження на основі наявних антен. Запропонована антена забезпечує високий коефіцієнт підсилення для потрібного діапазону частот, має VSWR менше двох і має гарне узгодження імпедансу на |S11| < – 10 дБ. Рекомендовану антену можна використовувати для високочастотних програм 5G, оскільки вона резонує на частотах міліметрових хвиль. Ці видатні результати вказують на те, що запропонована антена буде респектабельним варіантом для програм 5G мм-хвиль.

Ключові слова: Ansys HFSS, Компактний розмір, Вбудована подача, Мікросмугова антена, Додатки 5G, Патч із прорізами.