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A METASURFACE BASED HIGH GAIN PATCH ANTENNA FOR FUTURE MULTIBAND WIRELESS COMMUNICATION

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***Abstract*- This paper presents a novel high gain metasurface (MS) antenna. The antenna structure consists of a slotted square patch in a fractal shape, integrated with a metasurface layer stacked on Taconic RF-30 dielectric material. The individual cells are arranged periodically, creating a 5 $\times$5 layer configuration. The proposed antenna is designed with physical dimensions of 290$\times$290 mm^2 and achieves a maximum gain of 13.3 dBi at a frequency of 2.2 GHz. Moreover, it achieves a satisfactory minimum reflection coefficient of -10.9 dB. The design process and analysis were performed using the CST MWS simulation software. Based on the performance results obtained from this study, the suggested antenna can be considered suitable for applications in 5G communication.**

keywords: **metasurface, patch antenna, gain, reflection coefficient, CST.**

I. Introduction

In the last century, interest in metamaterials in wireless communications has become very important. Therefore, it is beneficial in reducing the sizes of devices used in communications, such as antennas, filters, etc.; This is due to its ability to direct waves, which allows it to be used with multiple layers of super-substrate [1]. By using the process of superstrate layers of metamaterials into a radiation source that runs along an existing wavelength (λ), this method can significantly improve performance coefficients and provide high protection for the radiation source from external sources. As a result of the progress of this technology, new applications have emerged within Communications fields, especially in antennas.[2]. It was found that the use of metamaterials improved the characteristics of antennas in terms of gain, physical dimensions, and radial pattern. Microstrip antennas are known to be lightweight and highly capable of manufacturing, and this technology is widely adopted in wireless communications.[3]. As a result, a lot of research focuses on metamaterials to improve the performance of antennas and reduce their size. The wavelength within the substrate may be related so that the strip antennas are small. The use of substrates with high permittivity and permeability will not significantly reduce the size of the antenna. [4]. However, Natural materials have limitations when achieving high values and permittivity. For this reason,

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the significant role comes in that synthetic materials fuse with natural materials, and this fusion improves the antenna's performance[5]; the magnitude of the antenna gain is significantly reduced [6].
The researchers studied the effect of metamaterials on the correction performance of antennas [7]. The study focused on metasurface to protect antennas that need protection from environmental influence. It has become clear that metasurface can also significantly improve antenna performance by placing technically designed substrates [8]. With studied distances of half a wavelength above the surface antennas' surface, the researchers noticed that their characteristics enhance the power of high gain. The researchers also studied the thickness of the insulating material in each multilayer core to determine its performance on the antennas [8, 9]. This study aimed to assess the possibility of improving the performance of antennas by using different materials. The results demonstrated that after modifying the design parameters and configuration of the superstrates, achieving high and improved antenna performance, such as enhancing protection against environmental factors and increasing gain [10-12]. Additionally, the study introduces the use of metamaterials as part of the antenna superstrate to enhance both the gain and beam-splitting capabilities. To optimize performance, two different patch designs were developed [13]. The first patch focused on improving the reflection coefficient in terms of installing and adjusting the second patch, specifically to achieve optimal performance of the reflection coefficient, and this is to ensure the best possible results for the reflection coefficient [14].
The first patch was designed in the shape of a rectangle with openings side, which results in no current passing through these openings, allowing it to work with high efficiency across the range between 1-6 GHz, and this antenna ensures work within the scope of various communications [15]. On the other hand, two antennas have been designed. The second is to correct and increase the reflection coefficient of the antenna, which provides a good range that extends from 1.8 to 5.9 GHz. This part allows flexibility to accommodate more bands in the communications field and improves signal transmission. Both designs have succeeded in enhancing high gain. [16]. This enhancement in performance leads to an improvement in the radiation pattern, which leads to very high coverage and effectiveness in receiving the signal. After the results are presented and analyzed by the antenna parameters, a very effective technique is used to determine the cell parameters called MTM (Metamaterial) [17]; this information and the properties include metamaterials such as permittivity, refractive index, transmittance, and high gain. By describing the antenna's performance and improving it based on accuracy parameters, researchers have discovered that metamaterials achieve high results with excellent efficiency. The combination of MTM and microstrip antenna is suited to several applications over the frequency of 2.2 GHz. This frequency fits in mobile communications, Wi-Fi, and Wireless communications. Generally, these changes in the materials used have led to the development and improvement of Accuracy in wireless communications, which can be used at more comprehensive frequencies and higher capabilities[18, 19]. The proposed MTM antenna is designed to meet the ever-evolving world of 5G technologies. It effectively covers the main frequency band of 5G spanning from 3.3 GHz to 3.6 GHz. This state-of-the-art solution ensures optimal performance and seamless connectivity for a wide range of applications in this rapidly expanding wireless network landscape. Due to the advanced design and use of metamaterials, this antenna is set to change the way we experience and use the power related to 5G technology.

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II. ANTENNA CONFIGURATION

At the beginning of the design process, various factors that affect the antenna characteristics were carefully considered [20]. These factors included substrate thickness, electrical dielectric constant, and permittivity losses. After careful evaluation, they resolved to use Taconic RF-30 (lossy) as the substrate material for our conventional and proposed design. TACONCRV-30(lossy) is a substrate material with specific properties that suit high-frequency applications well [21, 22]. One of the main advantages of the Taconic RF-30 (lossy) is its ability to maintain controlled impedance and ensure efficient signal transmission with a dielectric tolerance of (εr) 3, loss tangent ($\tan\delta$) of 0.0014 and a dielectric thickness of 1.6 mm [23]. This makes its use highly recommended in structures where signal loss management is critical. In addition, this base material has been widely recognized for its reliability in the design of RF and microwave circuits. Its excellent performance under various conditions makes it an indispensable choice when designing circuits and antennas that require stable and reliable results. The selection of the Taconic RF-30 (lossy) allowed an essential step towards achieving optimal antenna characteristics through effective management of signal loss [24].

A. The Patch Antenna Design

The first step of design, achieving optimal impedance matching between the feed line and the patch, is crucial for efficient performance. By utilizing a rectangular patch antenna with a side slot constructed from copper material, you have chosen a design that offers the potential for effective wireless communication [25]. The specific dimensions of 99.2×69.61 mm^2 for width and length provide a starting point for further optimization. Using a 50-ohm feed line, as depicted in Fig. 1 (a), allows for compatibility with standard equipment and ensures proper signal transmission. The dimensions provided in Table I will serve as valuable reference points throughout the design process[26]. It is important to note that achieving perfect impedance matching is essential for efficient operation and ensuring maximum power transfer between the feed line and the modified antenna. This will improve the signal quality and overall reliability of the system. To further improve design performance, it may be helpful to consider additional factors such as radiation pattern, gain, bandwidth, and efficiency [27].

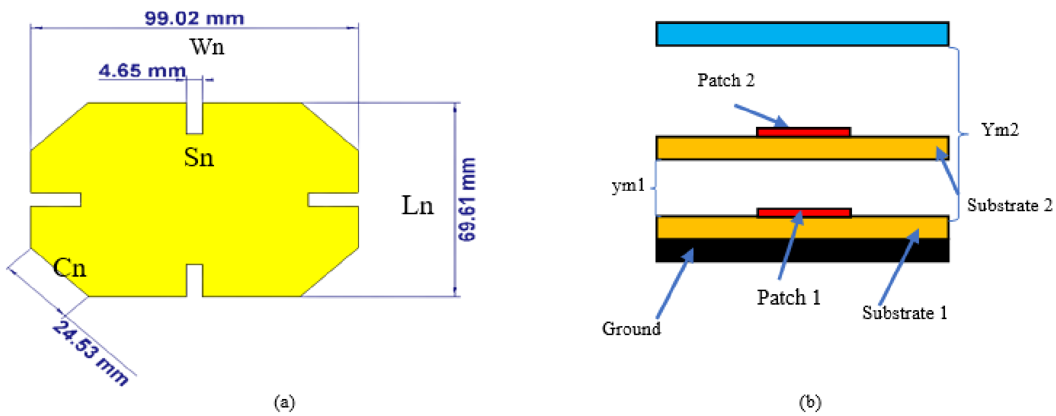

Figure 1: The structure of the antenna (a): patch antenna geometry (b): Schematic view of an antenna.

TABLE I
THE DIMENSION OF THE PROPOSED ANTENNA

Parameters	**Value (mm^2)**
W_n	99.2
L_n	69.61
S_n	4.65
C_n	24.53

In wireless applications, a super-substrate defines the gap between the antennas and the separation between the first and second rows [28]. It is important to note that the choice of material between these components significantly impacts this dielectric constant, as shown in Fig. 1. In this design, a 0.035 mm (ton) thick copper material was used to create the antenna. The feed lines, and type of patch the parameters were calculated to ensure the antenna resonated effectively at 5G sub 6 GHz band. By optimizing these dimensions and materials, effective radiocommunication performance at the desired frequency can be achieved [29].

Fig. 2 shows the super-substrate structure where the parameters are optimized and selected to achieve beam-splitting while maintain good gain and acceptable S11.

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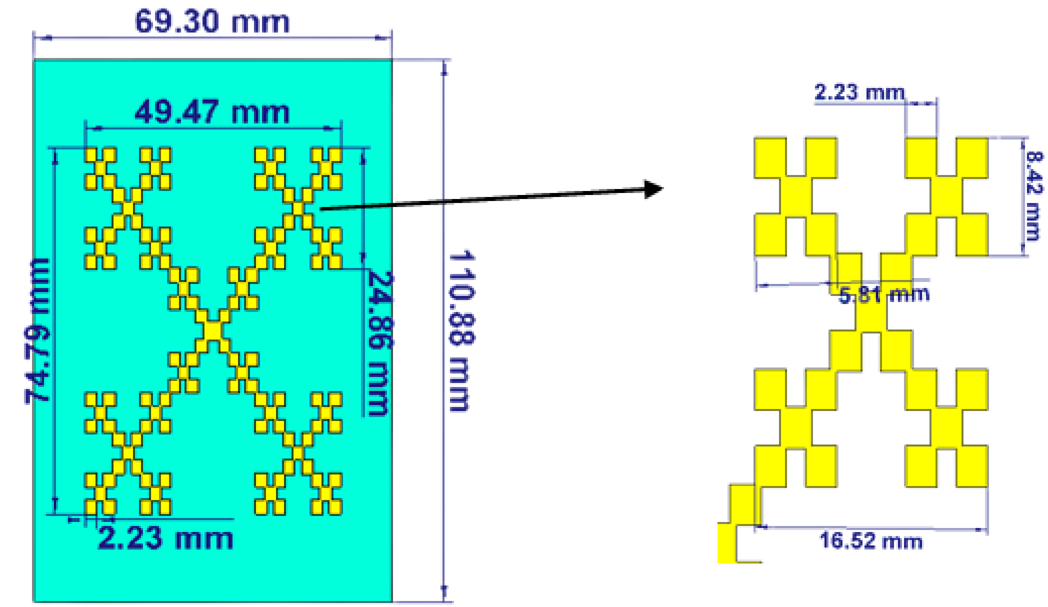

Figure 2: The supersaturate design structure.

Parasitic antennas present a suitable way to improve antenna performance. These antennas can achieve specific characteristics that contribute to their performance using passive parasitic elements. Unlike the radiating part of the antenna, which is directly connected to the supply line, parasitic elements do not have a direct electrical connection. However, they interact with the radiating part to increase the antenna power [30]. When parasitic elements are exposed to the radiated field generated by the patch antenna, they become excited and generate currents [31]. These induced currents have a mutual counteracting effect on each other, which helps reduce cross-coupling effects. This interaction between the radiation section and parasitic elements allows better control of factors such as radiation pattern, impedance matching, and gain. By strategically placing these passive elements around the antenna design, engineers can optimize its performance for specific applications or requirements. Overall, parasitic elements play a critical role in extending an antenna's capabilities and significantly improving its overall performance through their ability to interact with and modify antenna behavior without the need for direct electrical connections [32, 33]. An analysis and a comparison of antenna configurations, including isolation, impedance matching, and gain, are performed. The results of these studies confirm the essential advantages of combining parasitic elements. They can increase the separation between antenna elements and improve the overall performance of antenna systems. In summary, incorporating parasitic elements into the antenna design facilitates more precise control of mutual coupling and significantly enhance performance parameters such as isolation, impedance matching, and gain [34].

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B. Metamaterial Unit Cell Structures

The inclusion of synthetic materials into the system has fascinating effects, especially in terms of the refractive index of the medium [35]. Adding metamaterials increases the refractive index above the substrate's refractive index and improves the performance, as shown in Fig. 1(b) [36]. An application is to align arranged radio transmitters with antennas, increasing antenna gain. The design process of metamaterials is mainly based on considering the corresponding operating frequency. and investigates how a square configuration affects antenna performance and aims to achieve the best results [37]. By strategically placing synthetic materials in the ultrathin substrate and condensing them with the patch, the goal is to compensate for the emitted signal and improve overall signal quality. When the antenna was evaluated against its substrate, a significant increase in the emitted signal was observed [38]. This suggests that the use of manufactured materials can have a positive effect on signal transmission and reception.
The design in [39] has been further modified in this work to enhance the performance of the antenna. Also, the layers that make up the proposed antennas is demonstrated in Fig. 3, the purpose of the first layer is to act as a source for the second layer. Then, the second layer is improving directionality by splitting the radiation pattern into two beams. The spacing between these layers is crucial in determining the optimal outcome, as explained further in Table II. To give you a visual representation, Fig. 4 (a-c) show cases the final structure of this proposed antenna design.

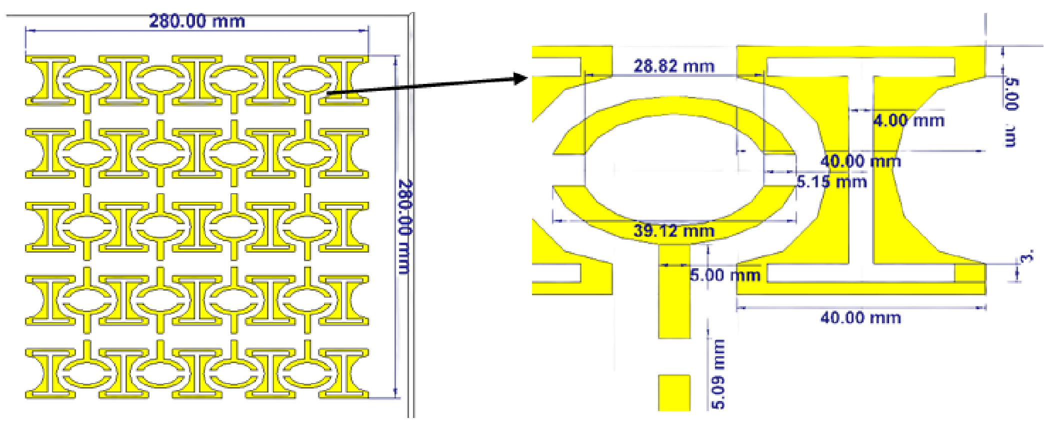

Figure 3: The MTM design structure.

TABLE II
METASURFACE DIMENSIONS

Name	Parameter	Value mm^2
Patch 1	A	99
	B	69.61
Patch 2	A	69.30
	B	66.47
Metasurface	MW	280
	MH	280
Gap Metasurface and Patch 1	Ym_1	30.5
Gap Metasurface and Patch 2	Ym_2	72.35

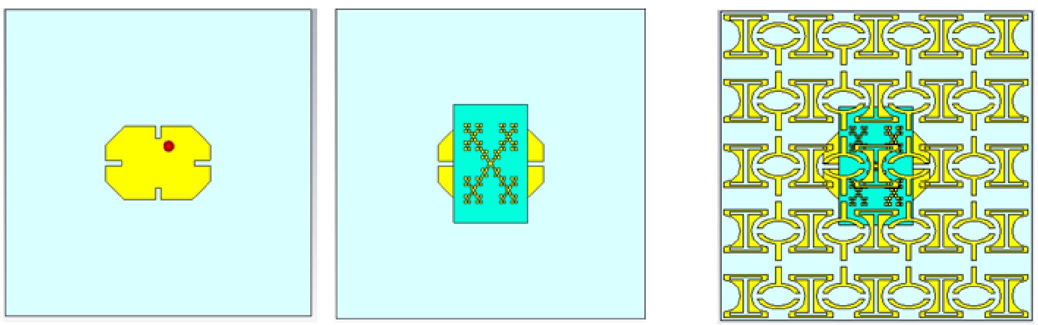
(a) (b) (c)

Figure 4: The final structure of the proposed antenna design (a): step 1 (b): step 2 (c): step3.

III. SIMULATION RESULTS AND DISCUSSION

This section introduces the simulation results and the performance evaluation of the proposed antenna. Fig. 5(a) illustrates the reflection coefficient characteristics at various design stages, providing an explicit knowledge of how the antennas evolved. Besides that, the resulting gain obtained from the proposed antennas is displayed in Fig. 5(b), showing the maximum value of gain is achieved. It is observed that, at the last step of the antenna design, a high gain of 13.3 dBi is achieved at its resonant frequency, which proves the significant advancements of the final antenna design that is proposed. For more validation, another simulator software called high-frequency structure simulator (HFSS) is used to analyze the proposed design. As illustrated in Fig. 5(c), reflection coefficient results show a satisfactory agreement with the results achieved by CST software over all the resonance frequencies have obtained. Meanwhile, the valuable insights into the radiation pattern outcomes in 2D and 3D indicate forward, and backward radiation are shown in Fig. 6. Table III illustrates a comprehensive comparison of the proposed antenna performance with previously related works in the literature. The antenna shows a significant improvement in gain compared with the results of the recent works that used parasitic or other technical ways to improve the gain.

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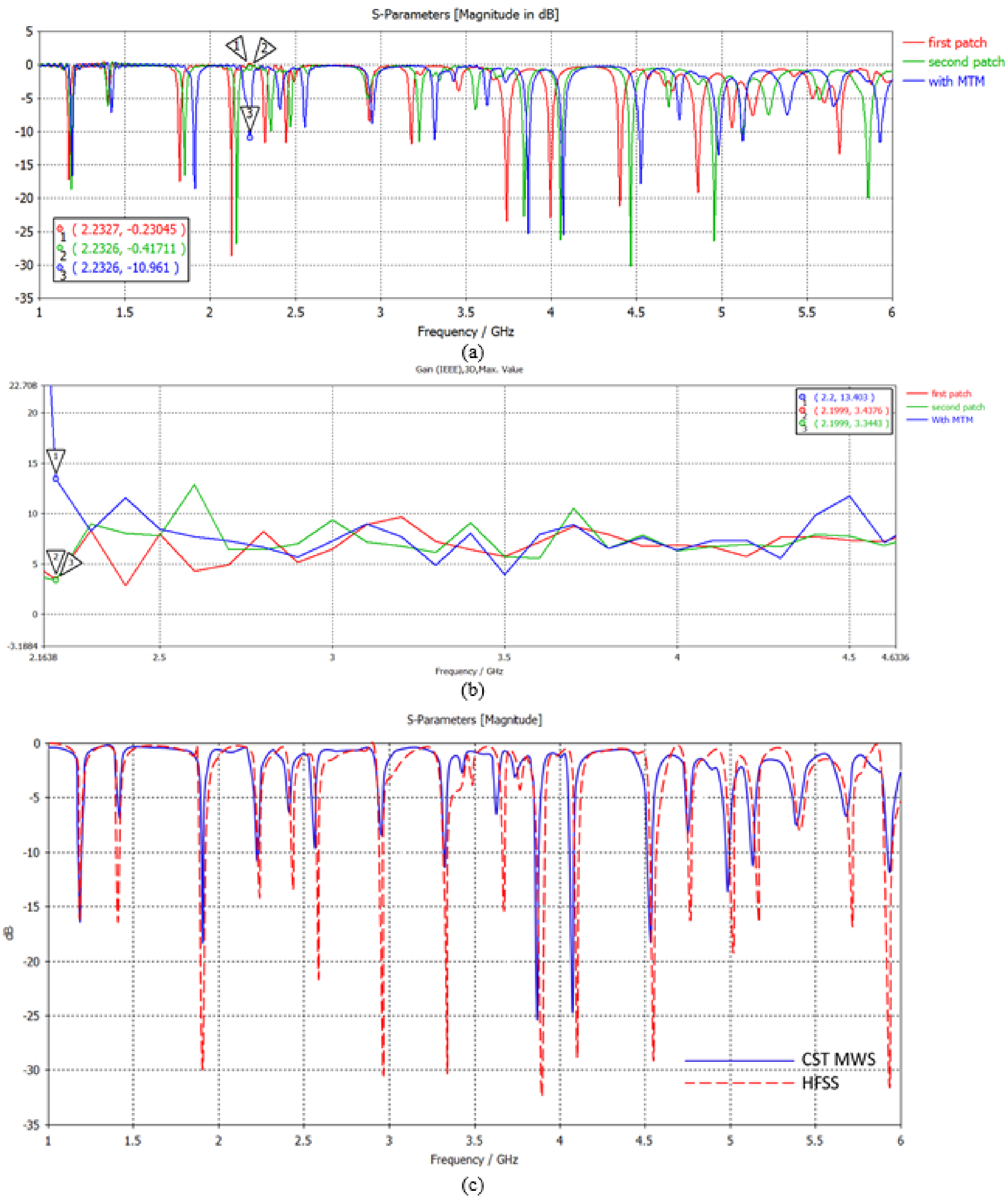

Figure 5: The simulated results of the proposed antenna (a): reflection coefficient of three stages of design (b): gain of three stages of design (c): comparison of the reflection coefficient using CST and HFSS.

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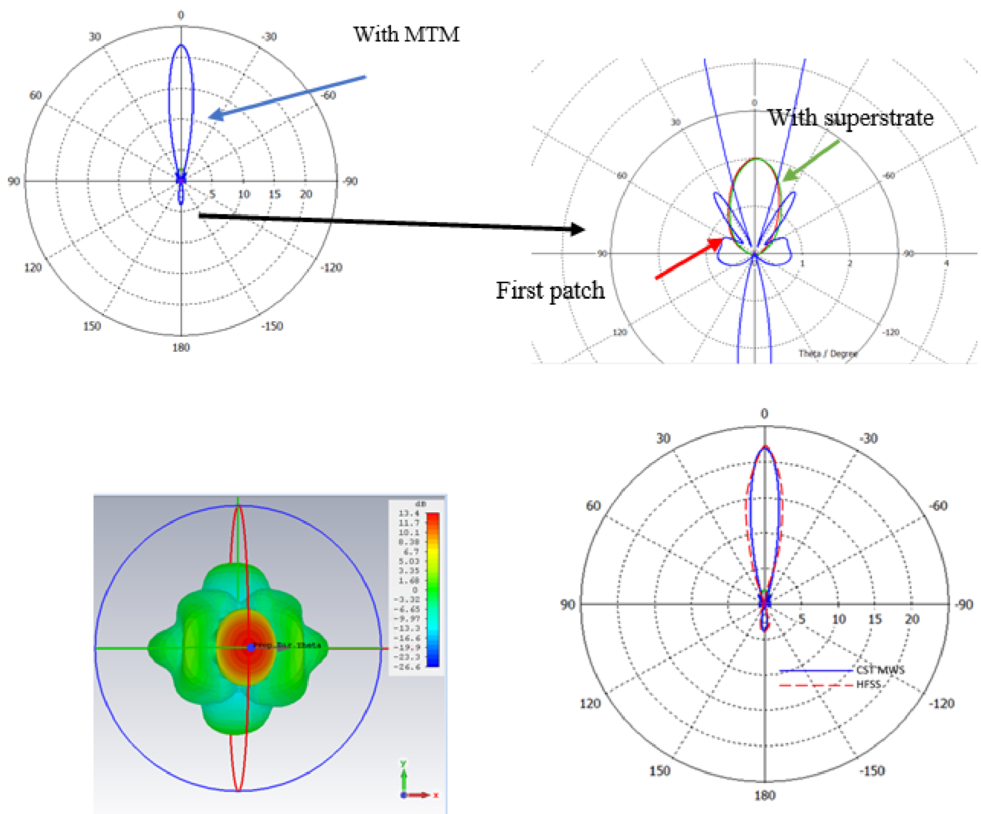

(b) (C)

Figure 6: Radiation pattern results of the proposed antenna at 2.2 GHz (a): 2D dimensions (b): 3D dimensions (c): with HFSS program.

Furthermore, the integration of absorber into the system is crucial in generating constructive interference in these two directions; this leads to two distinct split beams forming. By redirecting and concentrating the maximum radiation into these specific angles, the absorber enhances the radiation pattern. Moreover, it is essential to note that in the central region of the patch, especially near the feed point, there is a noticeable reduction in current flow. Consequently, the boresight direction is dominated by a null or void. However, this reduction is necessary for achieving optimal performance and desired radiation characteristics. Fig. 7 illustrates the diversion of the electric field and the flowing of current within the patch are altered. Furthermore, it shows how incorporating an absorber can significantly influence and enhance these aspects of radiation pattern formation.

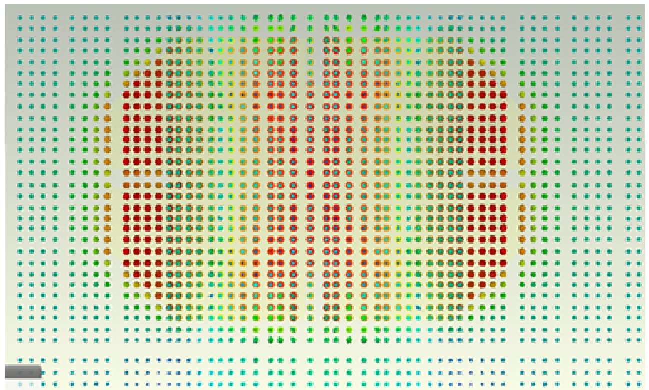

Figure 7: Current distribution result of the proposed antenna at 2.2 GHz.

A critical component of the CST software can analyze the reflection coefficient of the beam-splitting antenna. Fig. 8 demonstrated the simulation process of the reflection coefficient parameter of the antenna over the range of frequencies have proposed. More specifically, it covers the frequency bands of 1.9 GHz and 5.9 GHz. Its significantly observed that, at the frequency band of 1.9 GHz, the simulated reflection coefficient is approximately attained to -18.558 dB. On the other hand, at 5.9 GHz, the simulated reflection coefficient achieved about -11.6 dB. It concluded that the proposed antenna exhibited a high performance over the operating frequencies.

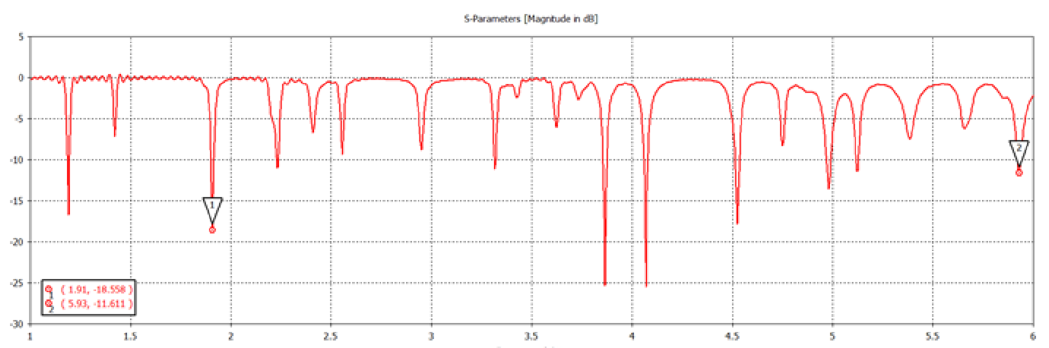

Figure 8: The reflection coefficient of the beam splitting at 1.9 and 5.9 GHz.

In addition, the antenna achieved a radiation efficiency of 75% at the frequency of 1.9 GHz. Moreover, the spread beam with a central lobe direction of 37 degrees adds to its versatility and potential applications. This characteristic allows for a more comprehensive coverage area, making it suitable for various communication or sensing purposes. Additionally, it is noteworthy that the antenna demonstrates an excellent performance inside lobes. With a result of -17 dB, it effectively minimizes unwanted radiation in off-axis directions. As a result of its high radiation efficiency of 71.13%, it can transmit and receive signals with increased effectiveness and reliability. Fig. 9 illustrates these impressive characteristics and validates the

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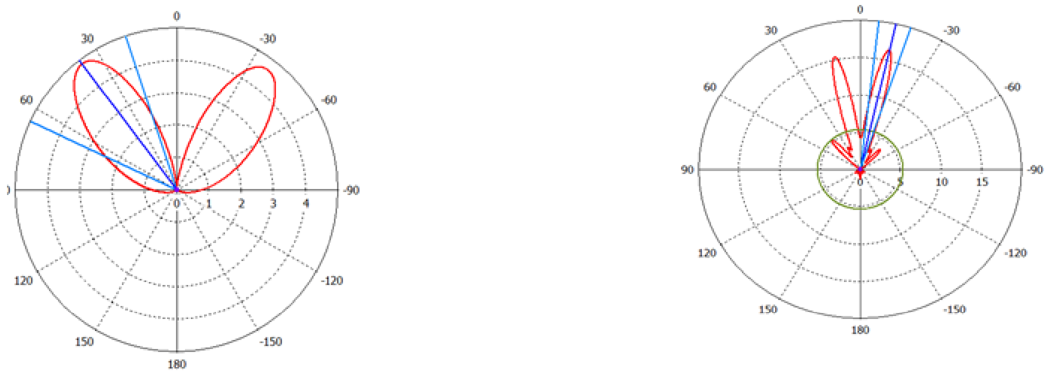
findings discussed above through illustrative representation. Ultimately, this analysis illustrates the capabilities and potential benefits of the microstrip patch antenna at a 1.9 GHz with an efficient radiation pattern and minimized side lobes.



(a) (b)

Figure 9: The radiation pattern of beam splitting with MTM and supersaturate (a) at 1.9 GHz (b) at 5.9 GHz.

Table III comprehensively compares the proposed antenna with previous works documented in the literature. The highlighted antenna stands out due to its remarkable features, including an enhanced impedance bandwidth and beam-splitting capability. Unlike its predecessors, this antenna maintains a consistent gain levels throughout the entire frequency band. The improved impedance bandwidth of the showcased antenna means it can operate effectively across a broader range of frequencies, making it highly versatile for various applications. Furthermore, its beam-splitting capability allows for efficient signal distribution and coverage optimization. This makes it an ideal choice for situations where space constraints are a concern. The comparative analysis in Table III demonstrates that the proposed antenna offers superior performance compared to existing solutions regarding impedance bandwidth, beam-splitting capability, gain levels, and overall form factor. This is very much in demand in 5G sub6 GHz applications where multiple bands provide versatility and single devices can operate for various applications. which is a desirable feature in 5G systems; in addition, beam-splitting is desirable in MIMO systems to enhance performance using single devices [40].

TABLE III
Comparison of the proposed antenna with previously reported work

Ref	**Antenna Size** (mm)^2	**Freq.** (GHz)	**Reconfigurable type**			**Peak gain** dB$_i$	**Technical type**
			Freq. Recon.	Beam Scan	Beam Splitting		
[41]	180×60	0.66-0.79 3.28-3.78	Yes	No	No	6.1	Ellipse-shaped ring patch
[23]	80.3×80.3	1 to 3	Yes	No	No	3.683	Parasitic
[42]	70×70	2.6	No	Yes	Yes	7.7	QMSIW
[22]	240×240	2.45	No	No	No	11.1	——
This work	290×290	2.2	No	No	Yes	13.3	Parasitic

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IV. CONCLUSION

This study proposed a new design of the patch antenna for future multiband wireless applications. The antenna has a 5×5 metasurface structure integrated with a fractal-shaped slotted patch. The varying metasurface unit cell shows a significant improvement in the antenna performance, especially the gain. This addition helps enhance the impedance matching of the proposed antenna over the operating frequencies in terms of achieving a minimum reflection coefficient. The proposed antenna operates at a resonant frequency of 2.2 GHz, exhibiting a high gain of 13.3 dBi. Moreover, other parameters have been evaluated using the same simulation software, such as the radiation pattern and the antenna efficiency. The proposed antenna obtained a unidirectional radiation pattern in a far-field region, making it highly valuable for medical investigations and defense service communications applications. All these features make the antenna suitable to use for different applications.

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CONFLICTS OF INTEREST

The author declares no conflict of interest.

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