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A Reconfigurable E-Patch Micrtostrip Antenna for 6G Applications

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Abstract: ***This paper presents the design of a novel reconfigurable E-patch microstrip antenna that can operate on 6G technology. This antenna is simulated using HFSS simulation software. The antenna is designed on a 2 mm x 1.4 mm Roger RT/duroid 5880 (tm) substrate fed by a microstrip line. The simulated S11 and VSWR results indicate that the antenna can operate at 118 GHz, a frequency considered to be part of the 6G spectrum. The antenna offers high gain, low profile, and high efficiency, making it suitable for future applications in the 6G technology. This antenna is also designed to be reconfigurable through a combination of PIN diodes and slot techniques, enabling dynamic frequency tuning. The results demonstrate that the antenna is reconfigurable in the frequency range of 110 GHz to 182 GHz.***

Keywords: 6G, Microstrip Antenna, E-Patch, Reconfigurable

I. INTRODUCTION

In the era of wireless communication evolution, the demand for high-speed data transfer, ultra-low latency, and ubiquitous connectivity continues to drive the development of next-generation communication systems. As 5G technology begins to establish its presence globally, researchers are already exploring the potential of 6G communication networks to revolutionize further the way we interact with digital information.

The fifth-generation (5G) wireless communication technology has brought unprecedented improvements in data rates, latency, and connectivity. However, as the demand for higher bandwidth and faster communication continues to grow, researchers have already started envisioning the next leap in wireless technology, known as 6G. At the heart of 6G networks lie antennas, which serve as the interface between electronic devices and the wireless medium [1]. Microstrip antennas, with their compact size, low profile, and ease of integration, have emerged as a promising candidate for 6G applications. Microstrip antennas are a type of printed antenna that is widely used.

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Used in modern wireless communication systems due to their numerous advantages. These antennas consist of a metallic patch placed above a grounded substrate, typically a dielectric material [2]. The patch and ground plane are connected through a feedline, which excites the patch and generates electromagnetic waves. Microstrip antennas offer flexibility in design, ease of fabrication, and compatibility with integrated circuit technology [3], making them suitable for various applications, including 6G communication.

The GSM Association, an industry group representing over 800 mobile operators worldwide, predicts that 6G technology will start commercialization by 2030 [4]. 6G technology is expected to be 100 times faster than 5G, with data speeds reaching one terabit per second (1Tbps). It will also have lower latency, which is the time taken for a signal to travel from its source to its destination. 6G is expected to have a latency of fewer than 1 millisecond, making it ideal for applications that require real-time communication, such as virtual and augmented reality, autonomous vehicles, and remote surgery.

In the context of 6G communication systems, several advancements are being made to enhance the performance of microstrip antennas. These advancements include multiband operation, beamforming, Multiple Input Multiple Output (MIMO), millimetre wave and Terahertz communications, integration with Metamaterials, and energy efficiency. However, several challenges need to be addressed to realize the full potential of microstrip antennas in 6G networks, such as bandwidth efficiency, power handling, integration with reconfigurable technologies, and environmental considerations, where antenna performance can be significantly affected by environmental factors such as temperature, humidity, and surrounding structures [5].

One of the most significant changes 6G technology is expected to bring is the integration of artificial intelligence (AI) to enhance its capabilities. This will enable the technology to learn and make decisions in real time, making it more efficient and adaptable to changing network conditions and user requirements. 6G technology is also projected to have a broader frequency range, reaching frequencies up to 10THz, which is 10 times higher than the maximum frequency used in 5G [6].

Antenna reconfigurability is a transformative feature in modern wireless communication systems, enabling a single antenna to dynamically adjust its frequency, radiation pattern, polarisation, or impedance in response to varying operational requirements and environmental conditions. This capability is achieved through various mechanisms such as electrical tuning, mechanical adjustments, or the integration of advanced materials like liquid crystals and metamaterials. Reconfigurable antennas enhance the flexibility and

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efficiency of communication networks, supporting adaptive beam steering, frequency hopping, and polarization diversity, which are essential for applications in cognitive radio, multi-band communication, and adaptive radar systems. By enabling real-time adaptability, reconfigurable antennas significantly contribute to the optimisation of spectrum usage, improvement of signal quality, and enhancement of overall system performance [7].

In the pursuit of high-performance microstrip antennas for 6G applications, researchers have explored various design techniques to achieve desirable characteristics, including wide bandwidth, high gain, and compact size. One prominent approach is the use of metamaterials to enhance antenna performance. Metamaterial-inspired structures, such as frequency selective surfaces (FSS) and electromagnetic bandgap (EBG) structures, have been integrated into microstrip antenna designs to achieve improved radiation characteristics and bandwidth enhancement [8]. These metamaterial-based antennas offer the flexibility to tailor the electromagnetic properties of the antenna, enabling efficient utilization of the available frequency spectrum in 6G networks. Furthermore, advancements in materials science have enabled the development of novel substrate materials with superior dielectric properties, allowing for the miniaturization and performance enhancement of microstrip antennas. Dielectric resonator antennas (DRA) integrated with microstrip feed networks have shown promise in achieving wide bandwidth and high radiation efficiency in compact form factors suitable for 6G applications [9]. Additionally, the use of advanced fabrication techniques such as additive manufacturing and inkjet printing has facilitated the realization of complex antenna geometries with enhanced performance characteristics [10]. The performance optimisation of microstrip antennas for 6G communication systems involves addressing key metrics, including bandwidth, efficiency, gain, and radiation pattern. One approach to enhancing antenna performance is the use of multiband and wideband techniques to support the diverse frequency requirements of 6G networks. Dual and triple-band microstrip antennas have been proposed to accommodate the simultaneous transmission and reception of multiple frequency bands, thereby increasing spectrum efficiency and enabling seamless connectivity in 6G environments [11]. Moreover, beamforming and beam-steering techniques have gained traction in microstrip antenna design to facilitate the implementation of massive MIMO (Multiple Input Multiple Output) systems in 6G networks [12]. Phased array antennas consisting of multiple microstrip elements controlled by phase shifters enable dynamic beamforming, allowing for precise steering of radiation patterns towards desired communication nodes [13]. Such beamforming capabilities are crucial for achieving ultra-high data rates and reliable connectivity in future wireless networks. Despite the significant progress in 6G microstrip antenna research, several challenges remain to be addressed to realise their potential in practical applications fully. One of the primary challenges is mitigating mutual coupling and interference between closely spaced antenna elements in massive MIMO systems. Strategies such as antenna element decoupling techniques, polarization diversity, and advanced signal processing algorithms are being investigated to overcome these challenges and improve the overall system performance [14]. Furthermore, integrating microstrip antennas with emerging technologies such as terahertz communication and quantum communication poses unique design and implementation challenges. The exploration of novel antenna structures and materials capable of operating at terahertz frequencies and supporting quantum information processing is essential for harnessing the full capabilities of future 6G networks [15]. 6G antennas are considered high-gain antennas. For example, in [16], a novel microstrip antenna's gains with a peak gain of more than 24 dB for sixth-generation (6G) cellular communication at a resonance frequency of 112.5 GHz are suggested and investigated. A couple of microstrip array antennas have been modelled and simulated using Rogers RO3003 microstrip laminates. Moreover, a couple of high-gain and broadband microstrip array antennas have been designed within a Finite Integration Technique (FIT) solver at Computer Simulation Technology Microwave Studio (CST MWS) software in a series-parallel feeding method for a resonance frequency above 107 GHz [17]. A Substrate-Integrated Waveguide (SIW) with dual outputs has been utilised in these antennas, along with a WR-08 waveguide that spans the 90-140 GHz frequency range. In [18], a new THz band frequency range antenna that operates at 250 GHz is designed to handle the enormous quantity of data traffic brought on by the increase in wirelessly linked devices. The antenna is made of copper material, and the substrate is made of polyimide film. Additionally, a dual-band, wideband, circularly polarised (CP) microstrip antenna is proposed for sub-6G applications. The antenna consists of an upper L-shaped radiator and two circular ground strips. This produces the right-handed circular polarization (RHCP) in the Wi-Fi (2.4- 2.48 GHz) and n77 (3.3-4.2 GHz) bands with the help of two circular strips at the left and right corners on the lower ground [19]. In [20], a new design of a D-band Rotman lens beam-steering microstrip array antenna at 110–145 GHz operating frequency is presented [21]. The proposed design can serve as a base for a large microstrip array, offering a more significant gain and a wider beam-steering angle, as reported in the research. Thus, the D-band Rotman lens beam-steering microstrip array antenna can be a proper candidate for next-generation backhauling cellular communication at the sixth generation (6G). At last, different novel designs of patch antennas at other frequency bands: V-shaped patch antenna at 2.4 GHz, and hexagonal slotted half-circular patch antenna at 4.29 GHz are designed with various shapes for different frequencies, since some applications require UWB, some applications require narrow bands but higher gain and some applications require different gain/radiation patterns at the same frequency. These antennas can be used in energy harvesting or biomedical applications.

The present work introduces a 6G microstrip patch antenna designed to resonate at a 118 GHz frequency, featuring a radiation patch and a specific feedline under specific conditions and equations. The output results show that the best performance occurs by reaching approximately -20 dB at 118 GHz with high efficiency. Reconfigurability is also an added feature of this antenna, where the antenna is shown to

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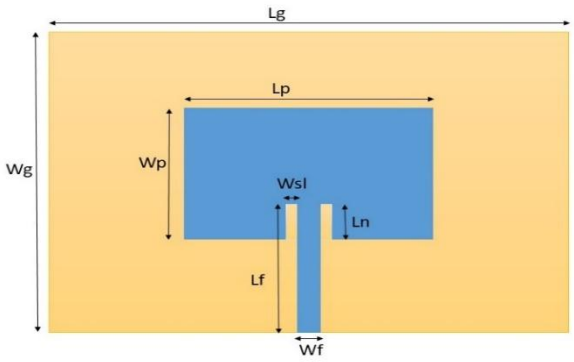
be frequency tunable between 110 GHz and 118 GHz by incorporating the slot techniques with a PIN diode.

The remainder of the paper is organised as follows. Section 2 provides a detailed description of the proposed microstrip antenna for 6G technology. Section 3 displays and discusses the simulation results. Finally, Section 4 is devoted to the main conclusions of this work.

II. THE PROPOSED MICROSTRIP ANTENNA

An essential component in developing 6G technology is the antenna design, which is responsible for transmitting and receiving signals in wireless communication systems. The proposed E-patch microstrip antenna design for 6G technology is a promising solution that operates at a resonant frequency of 118 GHz.

The proposed planar antenna is illustrated in Fig. 1. The antenna is designed using a low-dielectric-constant substrate material to achieve a compact size and low profile. It also incorporates an array of slots to enhance its bandwidth and increase the antenna's efficiency. The substrate used in this antenna is "Roger RT/duroid 5880 (TM)" material, with the following dimensions: X-Size = 2 mm, Y-Size = 1.4 mm, and Z-Size = 0.05 mm. The Z-size is the thickness of the antenna. The antenna has a full ground plane.



[Fig.1: Dimensions of the Proposed Antenna]

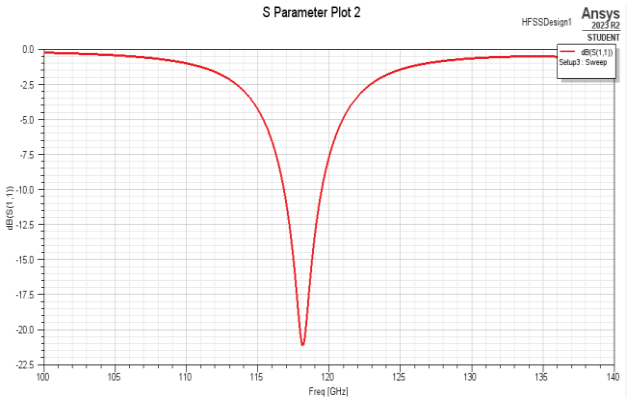
The feedline is connected to the microstrip patch and used to transmit and receive data. The antenna has the following dimensions:

- Lp = Patch Length = 1.185 mm
- Wp = Patch Width = 0.794 mm
- Lg = Ground Length = 2 mm
- Wg = Ground Width = 1.4 mm
- Lf = Feed Line Length = 0.56 mm
- Wf = Feed Line Width = 0.1 mm
- Ln = Notch Length = 0.19 mm
- Wsl = Strip Line Width = 0.05 mm

III. SIMULATIONS AND RESULTS

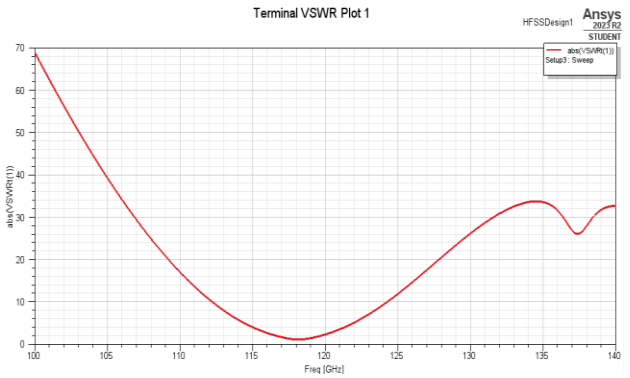
The proposed antenna is simulated using High-Frequency Structure Simulator (HFSS) software. HFSS is a finite-element method 3D electromagnetic simulation tool used in the design of radio-frequency and high-speed electronic devices and components. HFSS software uses computer-aided design (CAD) to model and simulate antenna designs, making it a popular choice for antenna engineers.

The simulated reflection coefficient plot of the proposed E-patch antenna is shown in Fig. 2. The return loss is approximately -21.25 dB at 118 GHz, indicating that the antenna can operate at this frequency, which is considered a 6G frequency.



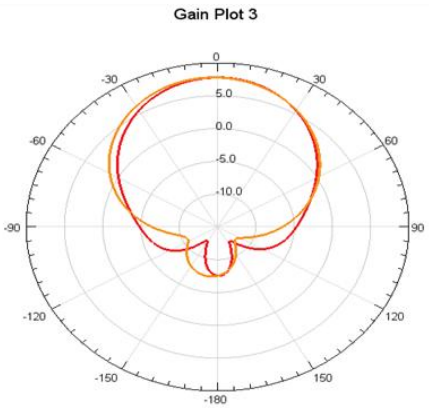
[Fig.2: Reflection Coefficient of the Antenna]

To ensure that the resonance frequency of this antenna is 118 GHz, the Voltage Standing Wave Ratio (VSWR) results are also implemented, and it is clear that the VSWR is zero at 118 GHz, as shown in Fig. 3



[Fig.3: VSWR Results]

The gain of the proposed antenna is shown in Fig. 4, which is approximately 7.8 dB. This is a good gain considering the antenna's small size. It is also clearly demonstrated that the antenna is directional.



[Fig.4: Gain and Radiation Pattern Results]

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This 6G microstrip antenna is highly efficient, with an impressive efficiency of 87%. This has been calculated using the formula:

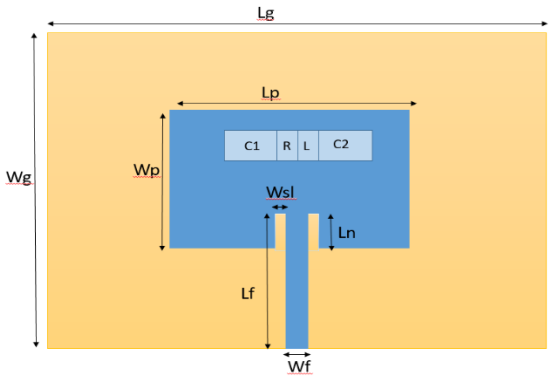
$$10^{\left(\frac{Gain-Maximum\ Directivity}{10}\right)} = 10^{\left(\frac{7.8-8.4}{10}\right)} = 87\%$$

It takes into account the gain of 7.8 dB and the directivity of 8.4 dB. The design has surpassed expectations, achieving remarkable efficiency that will significantly enhance the antenna's performance at this frequency.

IV. RECONFIGURABILITY

The reconfigurability of the 6G microstrip antenna design is achieved through a combination of PIN diode and slot techniques, allowing for dynamic frequency tuning. As shown in Fig. 5, a rectangular slot is added to the antenna with a dimension of 1 mm x 0.2 mm. This slot consists of 2 identical PIN diodes represented by a capacitor, an inductor, and a resistor as shown in Fig. 5. The size of the capacitor is 0.4 mm x 0.2 mm, the size of the inductor is 0.1 mm x 0.2 mm, and the size of the resistor is 0.1 mm x 0.2 mm. The inductor has a constant value of 1 mH, as does the resistor, which has a value of 1 ohm. However, the PIN diode has a variable capacitance, ranging from 0.01 pF to 1.7 pF.

By varying the capacitance between 0.01 pF and 1.71 pF, significant shifts in the resonant frequency were observed, achieving optimal performance at different specific values.

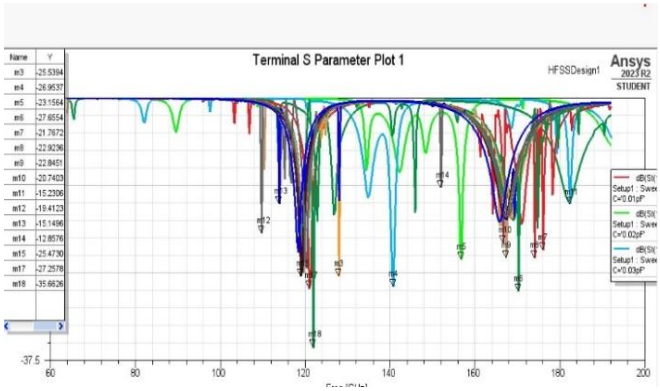


[Fig.5: Reconfigurable Antenna]

Notably, the antenna exhibited peak performance at 121, 122, 128, 140, 156, 170, 174, 176, 167, 166, 182, 109, 113, 152, 119, and 118 GHz. This wide range of tunable frequencies, spanning the 6G band and beyond, demonstrates the design's potential for versatile applications in high-speed wireless communication, sensing, and imaging. The integration of PIN diodes and slots provides a robust and flexible approach to reconfiguration, enabling dynamic adaptation to changing communication environments and signal requirements.

The best results were obtained at the following capacitances and frequencies, and the graphical results of the antenna's reconfigurability are shown in Fig. 6 below.

- 0.03 pF at 140.8 GHz
- 0.37 pF at 109.76 GHz
- 0.36 pF at 113.92 GHz
- 1.71 pF at 118.72 GHz
- 0.4 pF at 119.04 GHz
- 0.2 pF at 121.92 GHz
- 0.32 pF at 128 GHz
- 0.51 pF at 152 GHz
- 0.02 pF at 156.8 GHz
- 0.15 pF at 174 GHz
- 0.24 pF at 167.3 GHz
- 0.34 pF at 170.24 GHz
- 0.06 pF at 182.4 GHz



[Fig.6: Reflection Coefficient of the Reconfigurable Antenna]

V. CONCLUSION

In conclusion, the development of 6G technology is underway, and it is anticipated to usher in a new era of wireless communication, characterised by faster speeds, lower latency, and a broader frequency range. The proposed microstrip antenna in this work operates at 118 GHz, a frequency suitable for 6G technology. The antenna offers high gain, low profile, and high efficiency, making it ideal for future applications in the 6G technology landscape. The proposed antenna is also made to be reconfigurable in his work by combining slot techniques with PIN diodes. By varying the capacitance of the PIN diode, frequency tenability is achieved, allowing the antenna to operate on different frequencies within the range of 110 GHz to 182 GHz. As research and development for 6G technology continue, it is essential to monitor innovations in antenna designs.

DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

- **Conflicts of Interest/Competing Interests: Based on my understanding, this article does not have any** conflicts of interest.
- **Funding Support:** This article has not been sponsored or funded by any organization or agency. The independence of this research is a crucial factor in affirming its impartiality, as it was conducted without any external influence.
- **Ethical Approval and Consent to Participate:** The data provided in this article is exempt from the requirement for ethical approval or participant consent.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Author's Contributions:** The authorship of this article is contributed equally to all participating individuals.

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and Applications (ACME), a part of the High Performance Computing System (HPCS) conference.



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