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DESIGN OF 6G ANTENNA

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Abstract*— *The continuous advancement in wireless technology aims to provide enhanced and more engaging services. The forthcoming generation, 6G, is anticipated to support an immense volume of data traffic to accommodate the increasing number of connected wireless devices. To address this, a focus on large bandwidth and improved gain is essential, leading to the utilization of a new frequency region within the THz band. Given that 6G technology is still in its nascent stages and not yet fully defined, a comprehensive review of prior work on 6G is conducted to establish clear antenna design specifications. In this study, two types of antennas are developed: one with millimeter dimensions and the other with micrometer dimensions. The millimeter unit antenna exhibits a bandwidth of 1.69 GHz, ranging from 5.43 to 7.12 GHz, with a resonant frequency of 6.22 GHz. Meanwhile, the micrometer unit antenna, designed for 6G applications, features a resonant frequency of 5.7 THz. This paper also presents an analysis of gain improvement. The simulated results of the single-element 6G antenna demonstrate a wider bandwidth of 2.71 THz, spanning from 4.28 THz to 6.99 THz at the -10 dB level, a directive radiation pattern at both E-plane and H-plane, and a radiation efficiency of -166.8 dB.

Index Terms — 6G, 6G antenna, high data rate, wider bandwidth.

I. INTRODUCTION

Today, the rapid development of new wireless devices is a significant focus for scientists, researchers, and engineers who are continuously seeking ways to enhance and transform these devices to provide superior services and experiences. As a result, the sixth generation (6G) of wireless technology is predicted to be commercialized by early 2028 and widely adopted around 2030. Although 6G is not yet clearly defined, several white papers have been released by the University of Oulu, Finland [1], and Samsung Research [2].

Numerous industries and research institutes have also announced their commitment to conducting research on 6G [3].

Generally, as reported in [4], 6G is envisioned as an intelligent information system driven by advanced artificial intelligence (AI) technologies. In other words, it represents a revolutionary shift in wireless evolution from "connected things" to "connected intelligence." According to the white papers, this next-generation technology aims to provide enhanced mobile broadband (eMBB), ultra-reliable and low-latency communications (URLLC), and massive machine-type communications (mMTC).

Additionally, 6G is expected to support extended reality (XR), holograms, digital replicas, three-dimensional (3D) mapping, positioning, and sensing.

However, there are significant challenges in serving these advanced systems. With respect to the primary component of a wireless device, the antenna, achieving a very high data rate is essential to support the data traffic for these operations and the multitude of connected devices, which may increase to hundreds per cubic meter. Users should be able to transmit data at rates up to 1 Tbps. For instance, 0.58 Tbps is required to produce a hologram on a mobile device with a one-micrometer pixel size on a 6.7-inch display, amounting to 11.1 gigapixels.

Achieving such high data rates necessitates a wider bandwidth. To obtain bandwidths above 100 GHz, the terahertz (THz) frequency spectrum must be utilized, necessitating the extension of future generations into the THz region [5]. However, higher frequencies correspond to smaller wavelengths, resulting in antenna sizes ranging from micrometers to millimeters.

This presents a critical issue for fabricating and measuring such tiny antennas, as appropriate materials, technology, equipment, and facilities must be carefully considered.

The implementation of THz frequencies effectively reduces the size of 6G cells from small cells to "tiny cells," with radii of only a few tens of meters. Conversely, this frequency region faces challenges such as free space loss and molecular absorption. According to [6], certain implications for antenna design arise at THz frequencies. These include increased ohmic losses in perfect electrical conductors (PEC) with higher frequencies and the ability of dielectric and metallic interfaces to sustain surface plasmon polariton (SPP) waves. In addition to providing ultra-high data rates, gain improvement techniques can be employed to mitigate these losses, necessitating careful consideration of materials used in antenna design. The white paper also indicates that additional antenna gain, or antenna arrays are essential for improving positioning accuracy.

This paper presents a review of previous work on antenna design, covering frequency selection, fabrication techniques, material implementation, and performance for 6G applications. Additionally, a simulated antenna design is proposed for 6G applications at 300 GHz. The antenna features graphene as the radiator and flexible polyimide film as the substrate.

The gain of the proposed antenna is also examined and improved using a technique involving an additional substrate and air gap. The organization of this paper is as follows: Section II presents an overview of 6G antennas based on previous work. Section III details the proposed antenna design, simulated results, and analysis of gain enhancement. Finally, Section IV concludes the overall study.

II. Overview of the 6G Antenna

In [6], several important trends in antenna and radio frequency (RF) systems towards 6G are discussed. One notable trend is the transformation of antennas from the microwave region into the THz frequency band to achieve wider coverage. Additionally, the improvement of antenna performance through the use of new materials and metamaterials can address challenges related to the production of smaller antennas and resistance to interference, as well as the ability to control electromagnetic waves. Another trend is the evolution of antenna propagation channels using three-dimensional (3D) multiple input multiple output (MIMO) technology. Lastly, the development of new methods and indicators for measuring 6G antennas is highlighted. Previous works on 6G antennas have been thoroughly reviewed, covering aspects such as antenna types, frequency selection, material usage, fabrication processes, improvement techniques, and exhibited performance.

In [7], a circularly polarized (CP) conical horn antenna for the WM-864 frequency band (220 GHz to 330 GHz) is investigated. The conical horn is constructed from a brass block and manufactured using wire-cutting electrical discharge machining (EDM) techniques.

Measurements of the 300 GHz CP conical horn antenna show reflection from 270 GHz to 330 GHz with an S11 coefficient of less than −15 dB, resulting in an impedance bandwidth of 60 GHz. The right-hand circular polarized (RHCP) directivity is 18.3 dB at 312 GHz, and the 3-dB.

The axial ratio (AR) bandwidth is 7 GHz, ranging from 309 GHz to 316 GHz. Following this, [8] proposed a wideband directional antenna with common-mode current suppression characteristics using two radiating chokes. These radiating chokes are part of an antenna known as a wideband, high-efficiency electromagnetic structure (WHEMS). The antenna, made from Rogers 3003, is fabricated through surface metal etching and plated vias. The measured results show a bandwidth of 11 GHz, from 60 GHz to 71 GHz, below the -10 dB level. The gain ranges from 8 dBi to 10 dBi for frequencies between 60 GHz and 75 GHz, and the measured radiation efficiency is 95%. The measured 3-dB beamwidths for the E-plane and H-plane are 50° and 45°, respectively.

The next paper provides a specific review of low-THz wideband, high-gain antennas, and manufacturing processes for 6G [9]. This paper presents a wideband high-gain resonant cavity antenna (RCA) operating at 300 GHz. Although the antenna is fabricated at ten times the size of 300 GHz, i.e., 30 GHz, it is produced using metal binder jetting and 3D printing. The measured results indicate a frequency range from 29.5 GHz to 32.5 GHz below the -10 dB level, with realized gain ranging from 13 dBi to 16 dBi for 28 GHz to 31 GHz, a radiation efficiency near 88%, and a 3-dB beamwidth of 10%.

The last paper reviewed is [10], which explores the realization of an all-dielectric Huygens' metasurface at a frequency of 120 GHz. A planar transmit array antenna is designed by implementing a Huygens' unit cell for beamforming. The antenna is fabricated through laser drilling. The measured results show a bandwidth ranging from 119 GHz to 128 GHz at -10 dB, and a gain ranging from 32 dB to 34 dB within the specified bandwidth.

TABLE I
SUMMARY OF 6G ANTENNA PREVIOUS WORK

Ref. No	Antenna	Frequency	Material	Fabrication	Results		
					Bandwidth	Gain / Directivity	Others
[7]	CP horn antenna	300 GHz	brass block	wire-cutting EDM	60 GHz	18.3 dBic	AR bandwidth : 7 GHz
[8]	WHEMS	60 GHz – 75 GHz	Rogers 3003	surface metal etching and plated vias	11 GHz	8 dBi – 10 dBi	Radiation efficiency : 95% 3-dB beamwidth of E-plane and H-plane :50° and 45°
[9]	RCA	300 GHz Then downscaled to 30 GHz	metal	3D printing	2 GHz (20 GHz if not downscaled)	13 dBi – 16 dBi	Radiation efficiency : 88% 3-dB beamwidth : 10 %
[10]	Transmit array	120 GHz	all dielectric	laser-drilling	9 GHz	32 – 34 dB	-

The details of previous work are arranged in Table I. Another type of antenna proposed for 6G in other papers includes plasmonic nanoantennas operating at 474 THz, made from gold and silicon dioxide [11], and a 3x3 dipole lens. antenna at 300 GHz [12], metasurface antenna [13], gridded parasitic patch stacked microstrip antenna at 60 GHz and it is made by Taconic TLY and Arlon Cluclad [14], microstrip array antenna at 116.9 GHz using Rogers 3003 [15], and optical beam scanning antenna [16]. All the result given are in simulation and has different purpose of study, thus the information is not as detail as in Table I.

III. MILLIMETER ANTENNA DESIGN AND ANALYSIS

A. Antenna Design

The paper selects an operating frequency of 300 GHz. This choice is based on the positioning of THz electromagnetic waves within the frequency spectrum, which typically range from 0.1 THz to 10 THz. According to the IEEE standard, THz waves are defined within the range of 0.3 THz to 10 THz [17]. Additionally, the ITU World Radiocommunication Conference 2019 (WRC-19) has allocated frequencies for fixed and land mobile services in the range of 275 GHz to 450 GHz. Furthermore, the THz wireless communication standard IEEE 802.15.3d-2017 defines point-to-point exchanges within the lower THz frequency range of 252 GHz to 325 GHz.

The proposed antenna design is shown in Fig. 1. A microstrip patch antenna has overall width, *Ws* and length, *Ls* at 1.6 mm and 20 mm, respectively. The patch width, *Wp* is 11 mm, and patch length, *Lp* of 19 mm. FR-4 It's a flame-retardant glass-reinforced epoxy laminate material. with the resistivity of 10^{12} to 10^{15} ohm-cm
A fully ground plane at the next layer of substrate uses the same material as radiating patch. The antenna is fed by 50 Ohm feedline that has width, *Wf* of 02 mm. The optimization of antenna parameter length is summarized in Table II.

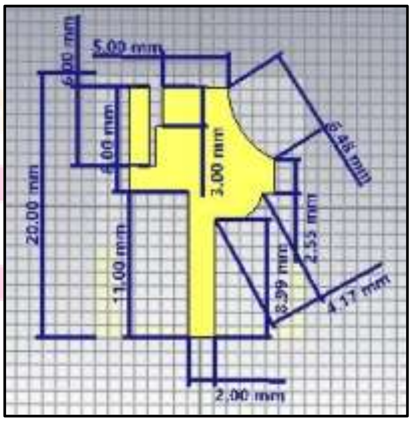

Fig. 1. [MILLIMETER ANTENNA]
The radiating patch and ground plane are represented by yellow colour, while substrate is represented by light white colour.

TABLE II
SUMMARY OF ANTENNA PARAMETER LENGTH

Description	Parameter	Length
Substrate width	*Ws*	16 mm
Substrate length	*Ls*	20 mm
Patch width	*Wp*	11 mm
Patch length	*Lp*	19 mm
Feedline width	*Wf*	02 mm

The proposed antenna is designed, simulated, and optimized using CST Microwave Studio to operate at a frequency of 6.2 GHz. The simulated results indicate a reflection coefficient magnitude of -22.97 dB, providing an impedance bandwidth ranging from 5.43 to 7.12 GHz at the -10 dB level, as depicted in Fig. 2. Additionally, Fig. 3 illustrates the simulated Farfield Directivity (Phi=90), with a main lobe magnitude of 177 dBi.

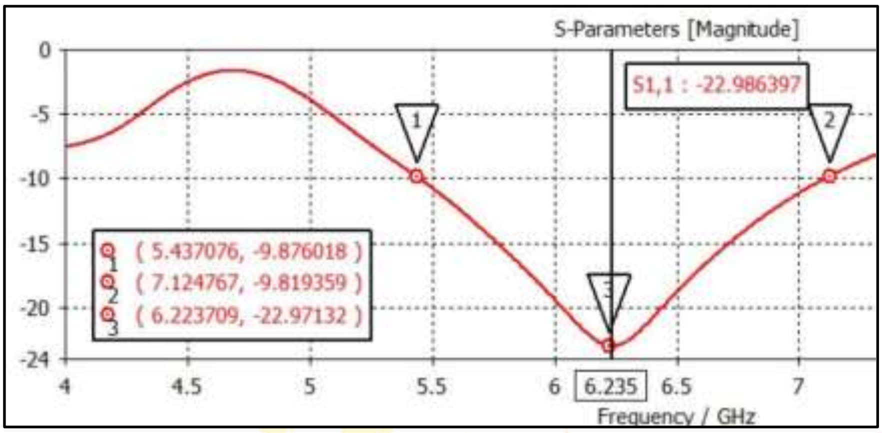

Fig. 2. S11 parameter Graph

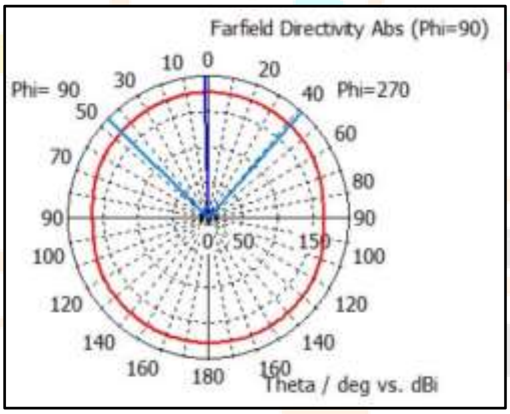

Fig. 3. FarField Directivity

From the simulated result, the VSWR ratio can also be analyzed, and it's as follows

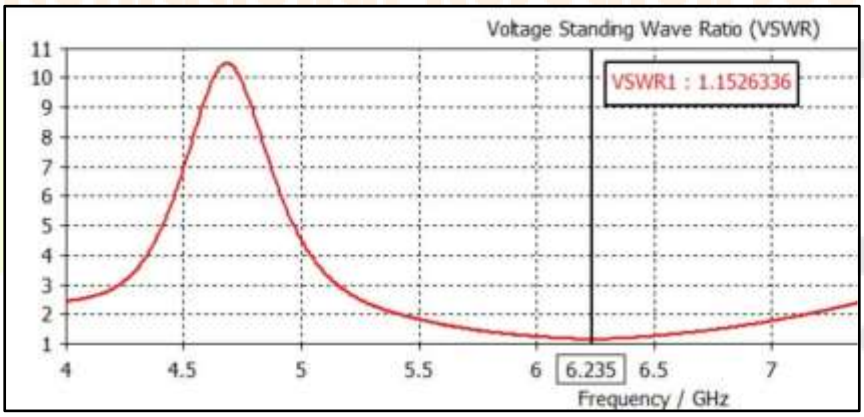

Fig. 4. VSWR

VSWR : (Voltage Standing Wave Ratio) indicates how well impedance is matched in a transmission line, with an ideal value of 1:1 representing perfect matching. As we can see in the graph it **1 : 1.52** so the values holds pretty good at the resonating frequency VSWR values closer to 1:1 are considered ideal, indicating better impedance matching and minimal power loss due to reflections. In most applications, a VSWR value below 1.5:1 is considered excellent, while values between 1.5:1 and 2:1 are acceptable for many applications. VSWR values above 2:1 may result in significant power loss and are generally considered undesirable.

IV. MICRO-METER ANTENNA DESIGN AND ANALYSIS

A. Antenna Design

The proposed antenna design, illustrated in Fig. 5, features a microstrip patch antenna with dimensions: overall width (Ws) of 1.6 mm and length (Ls) of 20 mm, while the patch width (Wp) is 11 mm and patch length (Lp) is 19 mm. Utilizing FR-4, a flame-retardant glass-reinforced epoxy laminate material, with a resistivity ranging from 10^{12} to 10^{15} ohm-cm, the design incorporates a fully grounded plane on the substrate's next layer, using the same material as the radiating patch. The antenna is fed by a 50 Ohm feedline with a width (Wf) of 0.2 mm.

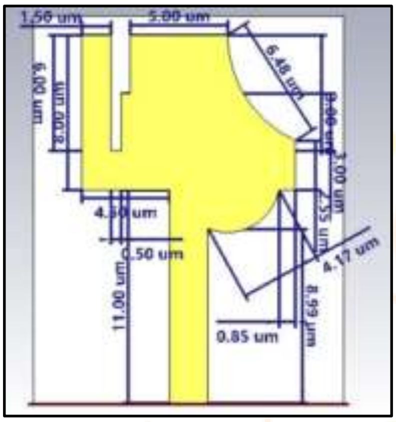

Fig. 5. [MICRO-METER ANTENNA] front view
The radiating patch is represented by yellow colour, while substrate is represented by white colour.

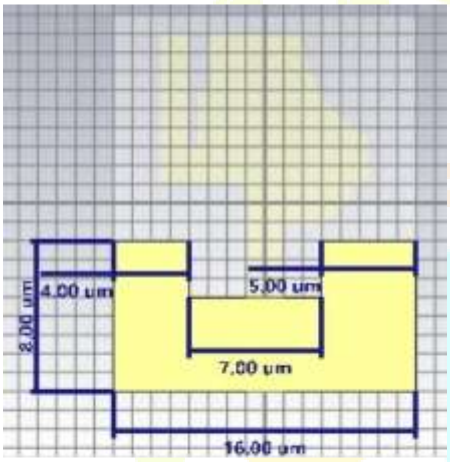

Fig. 6. [MICRO-METER ANTENNA] Back view
The ground plane are represented by yellow color

TABLE III
SUMMARY OF ANTENNA PARAMETER LENGTH IN MICRO-METER

Description	Parameter	Length
Substrate width	*Ws*	1.6 um
Substrate length	*Ls*	20 um
Patch width	*Wp*	11 um
Patch length	*Lp*	19 um
Feedline width	*Wf*	02 um

The proposed antenna is designed, simulated, and optimized using CST Microwave Studio for operation at a frequency of 5.7 THz. Simulated results show a reflection coefficient magnitude of -18.372 dB, yielding an impedance bandwidth from 4.28 to 6.99 THz at the -10 dB level, as shown in Fig. 7. Additionally, Fig. 8 displays the simulated Farfield Directivity (Phi=90), with a main lobe magnitude of 141 dBi.

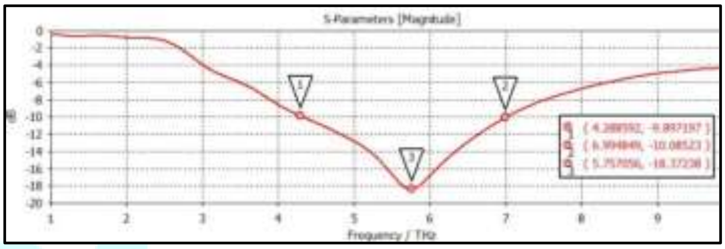

Fig. 7. S11 parameter Graph

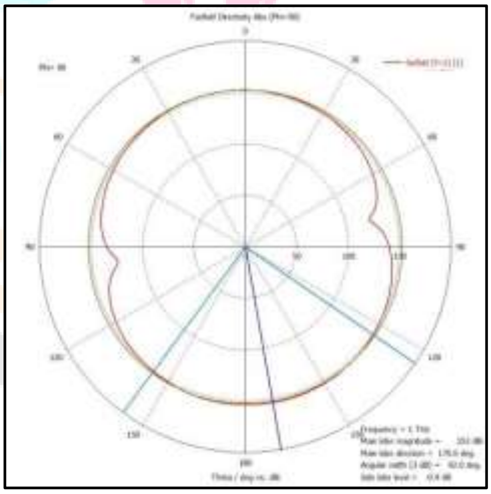

Fig. 8. FarField Directivity

From the simulated result, the VSWR ratio can also be analyzed, and it's as follows

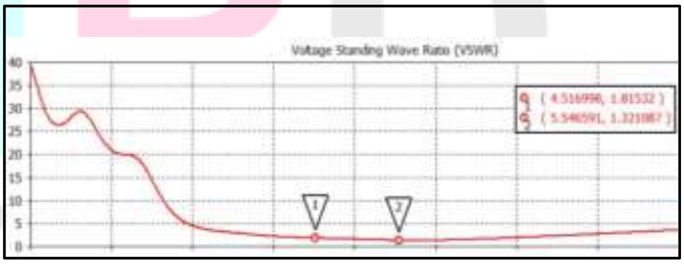

Fig.9. VSWR

VSWR : The Voltage Standing Wave Ratio indicates the impedance matching in a transmission line, with an ideal value of 1:1 representing perfect matching. In the graph, we observe a value of 1:1.81, which is still favorable at the resonating frequency. .

V. Conclusion

As the conclusion, the previous work of 6G antenna has been reviewed and presented completely. Each work has different objective, so there w e have different indication of frequency selection, antenna types and improvement technique. A two respective microstrip patch antenna for 6G application has successfully designed and simulated. The simulated result has achieved the operating frequency of 6.2GHz, and 5 . 7 THz and wide bandwidth of 1.69 GHz and 2.71 THz.

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