ARPN Journal of Engineering and Applied Sciences
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PERFORMANCE ENHANCEMENT OF GRAPHENE-BASED ELLIPTICAL PATCH ANTENNA FOR THZ APPLICATIONS

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ABSTRACT

The advancement of wireless communication applications has proliferated in recent years. The antenna design is crucial in evaluating the effectiveness of most of these wireless communication applications that demand extensive bandwidth and a lofty data rate. THz (Terahertz) band is becoming a key factor for advanced wireless communication applications. The design of microstrip patch antennas in the THz band is preferred as one of the most significant for advanced wireless applications. This paper proposed an elliptical patch antenna with a T-shape slot on the patch and partial ground methods to meet the speed demand of advanced wireless communication systems. The overall size of the antenna is $160 \times 120\ \mu m^2$. We investigated the antenna performance by using computer simulation technology (CST) simulation software. The simulation results indicate that our proposed antenna improves the bandwidth by 0.72 THz (720 GHz) with a return loss suppression of 12 dB. Moreover, the gain and efficiency of the proposed antenna show satisfactory enhancement. Based on the concept of a T-shape slot on the patch and partial ground method, we confirm the performance improvement of the proposed antenna through simulation results.

Keywords: THz band, graphene, T-shaped slotted patch, return loss, gain, bandwidth, CST.

Manuscript Received 24 July 2023; Revised 17 November 2023; Published 11 December 2023

1. INTRODUCTION

Modern technology needs to create a compact, integrated, and miniaturized circuit that leads toward higher frequency regimes. The THz (Terahertz) technologies have grabbed the attention of researchers in recent times by proving lots of capabilities that do not exist in conventional radio waves [1]. The improvement of the THz wave is expected to address the gap between the millimeter wave (mmW) and optical frequency ranges [2]. It is gaining popularity due to its demand in numerous wireless communication applications such as medical imaging for non-invasive diagnostics [3], Room temperature detection [4], or micro-bolometers [5] because of its non-ionizing nature and the ability to penetrate. It was confirmed [6] that THz radiation is almost harmless to human tissue.

To meet the criteria of THz band applications, a microstrip patch antenna (MSA) is used due to its wide applications. Moreover, MSA is inexpensive and has the features of easy fabrication, less weight, and compactness. Despite its wide variety with numerous applications, researchers face difficulties because of its relatively low power, narrow bandwidth, and high level of cross-polarization radiation. However, the vast bandwidth, minimum return loss, and enhanced gain are the most significant criteria for THz antenna design. Hence, several researchers have improved the performance of MSA by changing the parameters of the conventional antenna, such as varying the width of the substrate, size of the antenna, adding and cutting of slots or grounds [7], and shape of the antenna patches such as U-shape [8], Z-shaped slot [9]and H-slot [10], etc.

The author [11] proposed a PBG-type substrate for a wideband microstrip patch antenna, and then Amandeep *et al*. [12] modified the shape of the PBG-type substrate to hexagonal and obtained the performance enhancement of antenna parameters for high-speed THz application. At that time, the author [13] proposed a T-shaped patch antenna for further improvement. After that, the author [14] proposed an RMSPA antenna where sea foam was used as a subtract material and obtained a gain of 5.95 dB, a bandwidth of 130 GHz, and a return loss of -27 dB. Then the authors [15] changed the subtract material to Tefnol and obtained a gain of 4.71 GHz, a bandwidth of 210 GHz, and a return loss of -22.16 dB.

Recently, many researchers suggested using graphene as conducting material. Graphene has a noteworthy contribution to antenna applications where the frequency range varies from microwave to terahertz (THz) [16]. It has been grabbing the attention of researchers in recent eras due to its promising chemical, mechanical, thermal, and electrical properties [17]. It has 200 times faster electrical conductivity than silicon and a significantly high thermal conductivity of 5300 W/m/k. It has remarkable properties like transparency and flexibility and holds the status of the most robust material [18]. In our previous work [19], we used graphene as a conducting material and improved antenna performance satisfactorily. In this research, we have proposed a T-shape slot elliptical patch antenna with partial ground where graphene is used at the patch and ground layer as a conductive material, and FR-4 is used as an insulator at the subtract.

VOL. 18, NO. 19, OCTOBER 2023 ISSN 1819-6608
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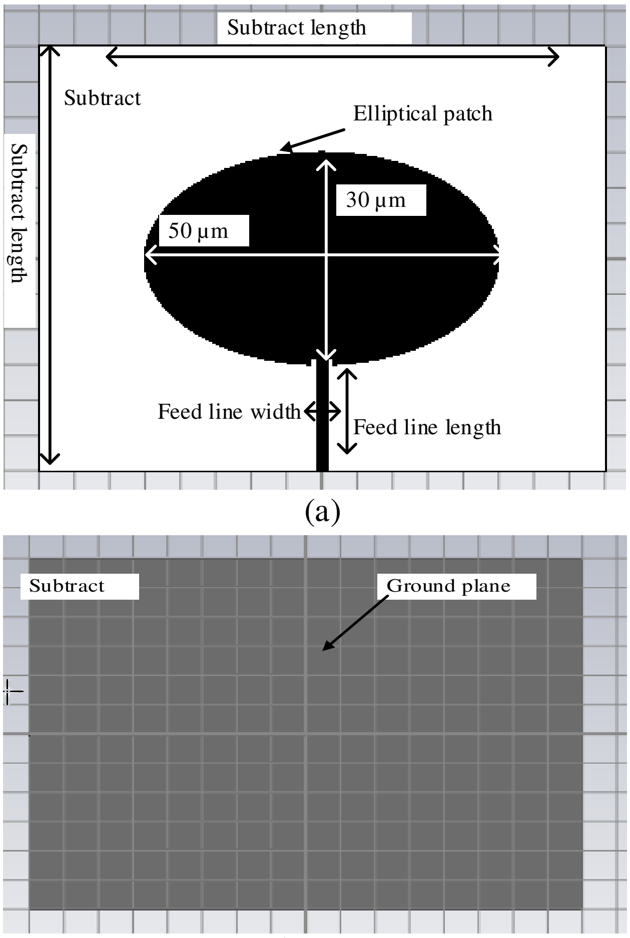

Figure-1. Conventional elliptical patch antenna (a) Top view (b) Back view.

This paper designed the antenna to operate at THz frequency bands. This paper investigates the performance of the proposed antenna by analysis of the antenna parameters such as return loss, antenna gain, and efficiency. All the previous work had some limitations. Some methods enhanced gain but failed to enhance other properties of the antenna. However, our proposed antenna is expected to enhance antenna performance in the THz band. The computer simulation technology microwave studio (CST-MWS) has been used to design, simulate, and analyze the proposed antenna. The key features of the proposed antenna are as follows:

- This antenna is impenetrable for working at our expected frequency band, THz.
- The gain of the antenna is relatively good.
- With enhanced bandwidth, this antenna can communicate at higher data rates.
- Our proposed antenna can be used for advanced wireless communication, optical communication, and future 5G mobile communication applications.

The rest of the paper is structured as follows. Section 2 describes the design parameter and procedure of

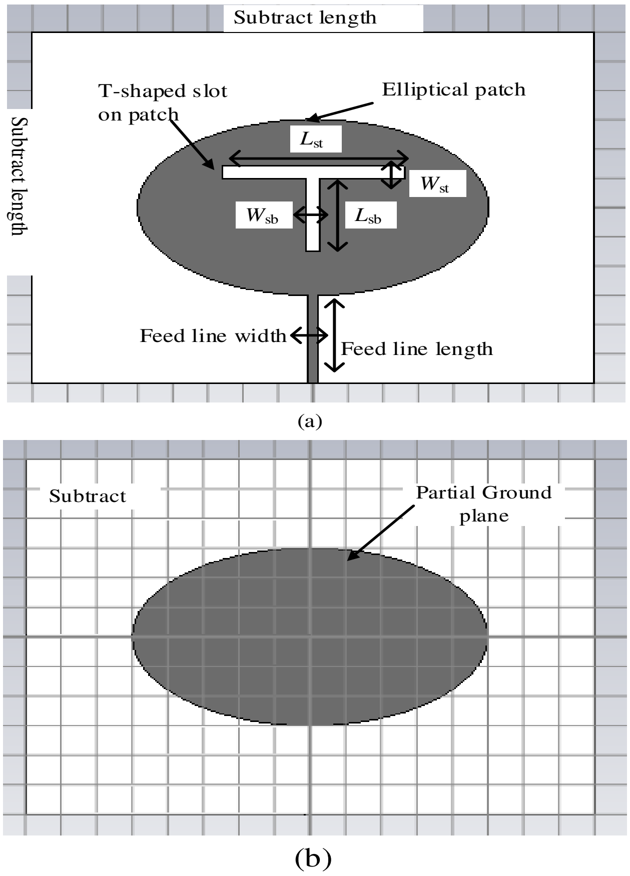

Figure-2. Modified elliptical patch antenna (a) Top view (b) Back view.

our proposed antenna. Then Section 3 investigates the antenna performance based on simulation results. Finally, Section 4 summarizes the work with conclusion.

2. DESIGN OF PROPOSED ANTENNA

Different geometric shapes have been used to design patch antennas with different substrates and conducting materials to operate the antenna at the expected frequency. Among them, the T-shape slotted patch with a partially grounded elliptical patch antenna (EPA) has been proposed in this paper for different communication applications. The size of the EPA is kept very small, with a length, width, and thickness of 160 µm, 120 µm, and 9 µm, respectively. In this paper, the patch is printed on FR-4 (lossy) substrates with dielectric constant, ϵ of 4.3, loss tangent (tan(δ)) of 0.02, and the subtract thickness is 6 µm. To design the antenna, graphene is used as a conducting material at the patch and FR4 as an insulator at the subtract.

Figure-1 and Figure-2 show the conventional and modified elliptical patch antenna, respectively. Both antennas have the same dimension with a frequency range from 1 THz to 4 THz. As the frequency range is in the THz regime, the antenna size has been reduced tremendously. The antenna consists of elliptical-shaped patches with a radius of 50 µm, and the patch and ground (GND) layer thicknesses are 1.5 µm. It is observed from Figure-2 that there is a T-shape slot on the patch. The

ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences
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input port relates to the patch through the feedline. To keep the line impedance of almost 50 Ω, we choose the feedline with length and width of 30 µm and 3 µm, respectively. Table-1 summarizes the parameters for the design of our antenna.

Table-1. Antenna parameters.

Parameter	Value (µm)
Substrate length (*Ls*)	160
Conventional GND length (*Lg*)	160
Substrate width (*Ws*)	120
Conventional GND width (*Wg*)	120
Thickness of substrate (*ts*)	6
Thickness of GND and patch (*tg*)	1.5
The width of the antenna patch and partial GND	30
The length of the antenna patch and partial GND	50
Feed line width (*Wf*)	3
Feed line length	30
Length of top side of T-shape slot (L_{st})	52
Width of top side of T-shape slot (W_{st})	4
Length of bottom side of T-shape slot (L_{sb})	26
Width of bottom side of T-shape slot (W_{sb})	4

3. RESULTS AND DISCUSSIONS

This paper uses the CST-MWS simulator to design and simulate the conventional and proposed antenna shown in Figure-1 and Figure-2. First, we design the antenna, as shown in Figure-1 and Figure-2, based on the design parameter of Table I and then simulate it to observe the antenna performance by analyzing the antenna characteristics such as compute return loss, gain, bandwidth, efficiency, and radiation patterns. Since only the antenna with good performance is fabricated, this simulator reduces the fabrication costs.

3.1 Return Loss and Bandwidth

The return loss is an essential parameter for analyzing the performance of an antenna. It measures the reflected power from the feed line. It is the ratio between the reflected power and incident power. It always has a negative value and only considers the value over -10 dB. A lower return loss indicates less power is reflected from the antenna.

Figure-3 shows the spectra of the return loss where the x-axis indicates the frequency in the THz range and the y-axis indicates the value of return loss in dB. For the investigation, we measured one of the standard S-parameters, S11, which indicates the reflection characteristics at the input port of the antenna. The solid red spectra indicate the conventional elliptical antenna and the solid green spectra indicate the proposed elliptical antenna.

It is evident from this figure that the value of return loss, S_{11}, for the conventional antenna at resonant frequency 1.80 THz is -17.14 dB, at 2.14 THz is -36.7 dB, at 2.28 THz is -44.91 dB. In contrast, for the proposed antenna, the value of S11 at resonant frequency 1.90 THz is -45.17 dB, at 2.07 THz is -56.54 dB, at 3.04 THz is -19.97 dB, at 3.33 THz -18.99 dB and 3.70 THz is -22.44 dB. It is noticeable from this figure that the minimum value of S_{11} for the conventional antenna is -44.91 dB at 2.28 THz, whereas the proposed antenna shows -56.54 dB at 2.08 THz. Hence, the proposed antenna shows a 12 dB improvement in return loss. Moreover, the bandwidth of the convention antenna is 1.84 THz (1.67 THz - 3.51 THz), whereas the proposed antenna is 2.56 THz (1.37 THz - 3.93 THz).

Therefore, the proposed antenna enhances the bandwidth from 1.84 THz to 2.56 THz. Hence, the bandwidth is enhanced by 0.72 THz (720 GHz) with the proposed antenna, which is approximately 1.5 times greater than that of the conventional antenna. This confirmed the improvement of the antenna bandwidth by implementing a partial ground plane technique with a T-shape slot on the elliptical patch. This proposed antenna is suitable for a wide range of wireless applications, such as radio astronomy, communications, sensors, and future 5G mobile communication.

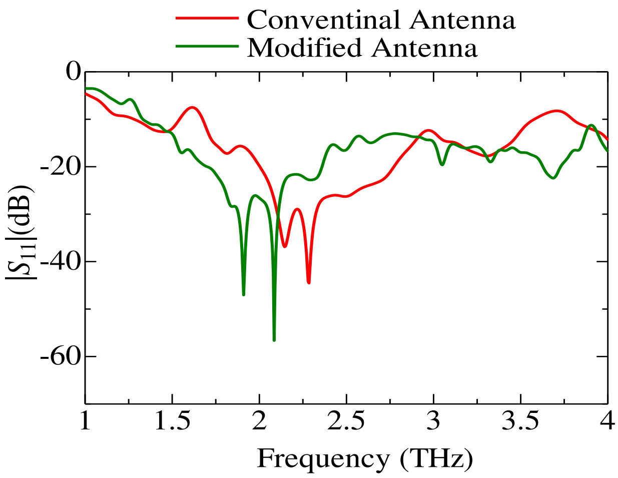

Figure-3. Spectra of S_{11}.

3.2 Gain and Antenna Efficiency

Antenna gain and efficiency are two important parameters for evaluating the performance of any antenna. Gain measures the radiated power in each direction, whereas antenna efficiency measures radiated energy in the air. Figure-4 and Figure-5 show the spectra for antenna gain and efficiency, respectively.

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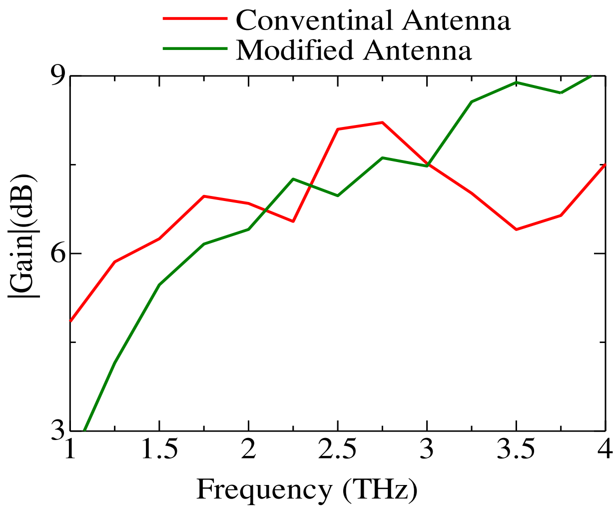

Figure-4. Spectra of antenna gain.

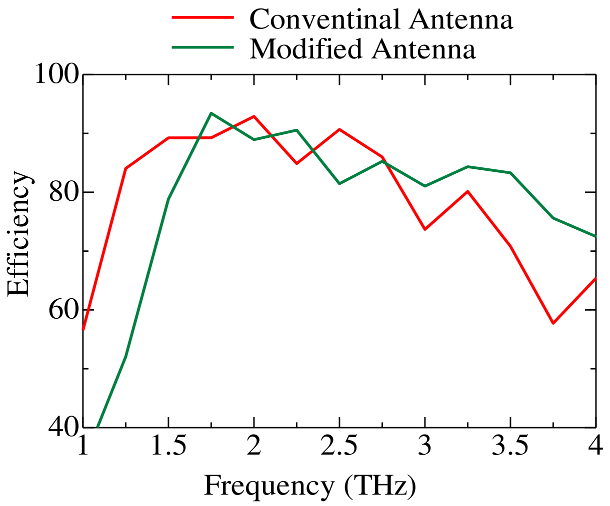

Figure-5. Spectra of antenna efficiency.

3.3 Radiation Pattern

It measures power in different directions. It is a key parameter for evaluating the performance of an antenna due to the role of an antenna in radiating. Figure-6 and Figure-7 show the radiation patterns for the conventional and proposed elliptical antenna in 1D and 3D views. In this figure, the red, yellow, green, and blue colors indicate the radiation level of the antenna from the highest value to the lowest value. It is evident from this radiation pattern that the proposed antenna has a maximum radiation power of 10.82 dB. It shows a satisfactory enhancement in antenna performance for supporting the THz band communication system.

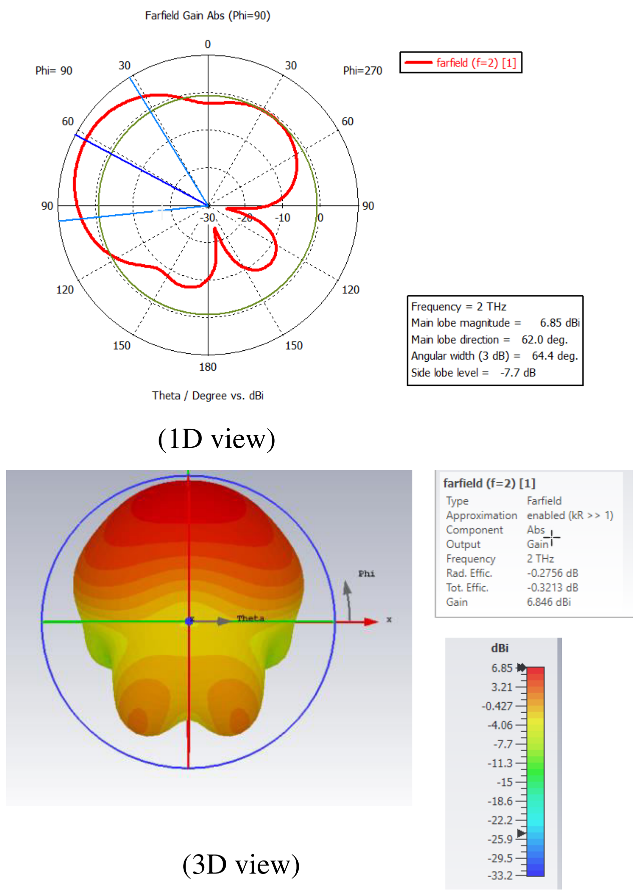

Figure-6. Simulated 1D and 3D radiation pattern for phi=90^0 at 2 THz frequency for conventional elliptical patch antenna.

4. COMPARATIVE ANALYSIS

It is evident from Table II that our proposed antenna size is smaller than the previously proposed antenna. Furthermore, our proposed antenna exhibits low return loss compared to another antenna. Moreover, the bandwidth, gain, and efficiency show enhancement to previously proposed antennas. Some conventional antennas exhibit higher efficiency at a specific frequency with lower bandwidths and higher antenna sizes. Admittedly, our proposed antenna is concise and more efficient than other antennas based on size, low return loss, enhanced gain, and higher bandwidth. Therefore, the elliptical path antenna with a T-shape slot and partial ground could be a better option in practical applications.

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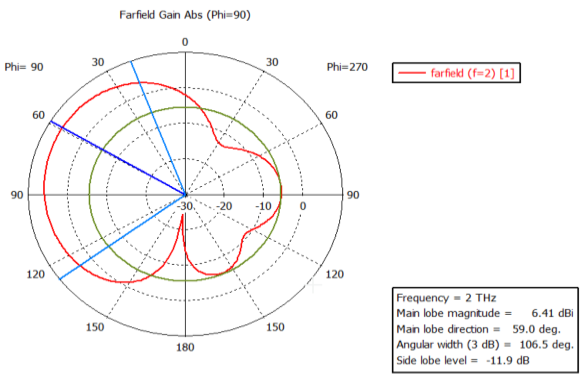
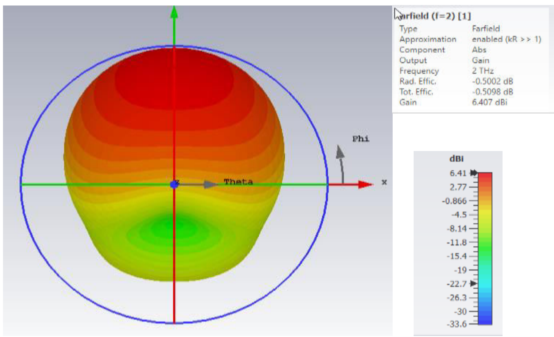
Table-2. Comparative analysis.

Ref.	**Size (μm^2)**	**S_{11} (dB)**	**Bandwidth (THz)**	**Peak Gain (dB)**	**Efficiency (%)**
[12]	950×950	-15.70	1.2	3.8	N/A
[13]	600×600	-19	0.10	8.82	54.9
[15]	170×170	-22.36	0.21	4.71	N/A
[20]	150×100	-28	0.30	3.81	86
[19]	170×170	-18	93.22	4.45	98.4
Conventional	160×120	-44.91	1.84	7.01	91.6
Proposed	160×120	-56.54	2.56	8.66	93.8



(1D view)



(3D view)

Figure-7. Simulated 1D and 3D radiation pattern for phi=90^0 at 2 THz frequency for modified elliptical patch antenna.

5. CONCLUSIONS

Designing a microstrip patch antenna with high gain, low return loss, and improved bandwidth is one of the significant challenges for researchers in the THz range. In this paper, an elliptical patch antenna with and without a T-shape slot on the patch and a partial ground slot is successfully designed and investigated. The improvement of the proposed antenna shows sufficient enhancement in return loss, gain, bandwidth, and efficiency. Moreover, the proposed antenna size is very compact compared to the previously proposed antenna. Therefore, our proposed antenna parades 0.72 THz (720 GHz) bandwidth enhancement, which is 1.3 times greater than the conventional one. Moreover, the proposed antenna enhances the gain by 1.65 dB, and the return loss is reduced by 12 dB compared to the conventional antenna. As a result, the concept of a T-shape slot and partial ground method confirms the performance improvement of the proposed antenna, and we validated it through simulation results. Hence, the proposed antenna is applicable for wireless communication and future 5G mobile communication in the THz frequency band.

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