Revolutionizing Wireless Communication: The Convergence of CNT and Antennas for Futuristic THz Communication

Atanu Chowdhury[1][a] and Soumya Sen[2][b]
[1]Calcutta Institute of Technology, Uluberia, West Bengal, India
[2]University of Engineering & Management, Jaipur, Rajasthan, India

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Abstract: This manuscript presents a circular patch Carbon Nano Tube (CNT) antenna having two “Z” slots and a defected ground structure (DGS) suitable for optical frequency applications. A semi-spherical layer of the Polyflon Cuflon layer(ε_r=3.41) is attached to the ground to enhance the gain resulting in an improvement in radiation efficiency. The proposed antenna dimension is 40 nm × 40 nm × 1.6 nm based upon a silicon substrate (ε_r=11). The proposed antenna covers a bandwidth of 2 THz to 6.5 THz. Without the attached layer, the maximum gain is 3.5 dB while the attachment of the layer increases it up to 6.1 dB. The Radiation efficiency is also improved from 62% to 81% by implementing the attachment. The overall structure is designed and simulated in HFSS 21.0 software.

1 INTRODUCTION

Microwave researchers are currently focusing on modern communication technologies and modulation techniques to address bandwidth challenges, aiming to enhance spectral utilization efficiency (PAULRAJ et al., 2004). These efforts also target improvements in data rates and frequency reuse. However, Shannon’s theory imposes an upper limit on channel capacity, even with advancements like MIMO technology. To overcome this limitation, researchers are considering higher bands applicable for optical frequency range communication, such as the band of 1000 MHz to 10 THz (Akyildiz et al., 2014). Recently, a “bow- tie” antenna has been optimized for communicating in between 110-292 THz, utilizing a glass as the base and an aluminium dipole antenna to optimize parameters (Kavitha et al., 2023).

Despite its potential, THz signal usage lags behind that of the electrical or optoelectronic field due to hardware limitations, particularly in THz signal generators and sensors. However, since the 1980s, the accessibility of nanosecond lasers and photo-conductive antennas has enabled several fields, like medical science, pharmaceutical-oriented research, and also pri- vacy, to utilize THz waves (Apriono et al., 2015; Car-valho et al., 2023). The advantages of THz communi- cation include enhanced directionality, data security, and reduced attenuation (Federici and Moeller, 2010). Nevertheless, higher atmospheric absorption limits its utility for short-distance communication. Despite high demand over the last 2 decades, hardware implementation for THz frequency range operation remains challenging.

In the realm of THz services, recent developments in- volve the creation of various metal-fabricated nano- antennas and array orientations, such as lens antennas, horn antennas and many more (Malhotra et al., 2017; Konstantinidis et al., 2015; Alazemi et al., 2016; Yu et al., 2020; Hao et al., 2017). Fabricating these high-frequency antennas poses challenges due to measurements in the nanometer range. Consequently, researchers are exploring alternative materials like graphene and carbon nanotubes to mitigate skin depth reduction associated with traditional materials like gold and copper. Recent studies have compared antenna materials and their performances for THz communication nanoantenna designs (Ghaf- far et al., 2019).

Moreover, simulations of an antenna optimized by a silicon lens having a silicon substrate have shown promise, with additional layers applied to the lens surface to boost effectiveness (Dash et al.,

[a] https://orcid.org/0000-0002-9323-4839
[b] https://orcid.org/0000-0002-6354-5206

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2020). Researchers are also examining broadband imple- mentations using the bow-tie antenna in conjunction with capacitive lines and a hemispherical silicon lens. However, further enhancements in electromagnetic properties are needed to improve radiation effective- ness (Wahyudi et al., 2017). Research indicates that a silicon lens is useful for the enhancement of the di- rectional capability of a light-conducting antenna on a Galium Arsenite base within the THz spectrum range (Jyothi et al., 2016). Additionally, ”bow-tie” antennas on a surface made of InP, combined with hemispheri- cal and bullet-type silicon lenses, have been utilized to eliminate surface waves, resulting in improved gain, efficiency, and a wider spectrum (Li and Song, 2016). This research article introduces a novel concept: A circular patch antenna with two ”Z” slots and a de- fected ground structure (DGS) has been developed for optical frequency applications. To enhance its gain and radiation efficiency, a semi-spherical layer of Polyflon Cuflon material (with a relative permittivity of 3.41) is attached to the ground. The antenna is designed with dimensions of 40 nm × 40 nm × 1.6 nm on a silicon substrate with a relative permittivity of 11. It operates within a bandwidth ranging from 2 THz to 6.5 THz.

Before attaching the layer, the antenna achieves a maximum gain of 3.5 dB. However, with the attached layer, the gain increases significantly to 6.1 dB. Additionally, the radiation efficiency improves from 62% to 81% with the implementation of the attached layer. The entire structure is designed and simulated using HFSS 21.0 software.

2 ANTENNA DESIGN & ANALYSIS

The proposed antenna is designed in a few steps on the silicon substrate. The volume of the substrate is 40 nm × 40 nm × 1.6 nm. In step-1, a simple circular horizontally aligned CNT patch antenna is designed with a radius of 7 nm and a feedline having a length of 17 nm, and a width of 2 nm. This structure is shown in Fig. 1(a). In step-2, the ground is defected to a rectangular shape as shown in Fig.1(b). In step-3, the circular patch is slotted with two “Z”-slots to enhance the coverage of the frequency band as shown in Fig. 1(c). In step-4, a layer of Polyflon Cuflon (ε_r=3.41) is attached to the ground as shown in Fig. 1(d). This is done to increase the gain as well as efficiency. As we all know the dielectric constant of the silicon substrate (ε_r) and air is 11 and 1 respectively. To counter this gap between these dielectric layers, a matching layer was needed. So, mathematically a layer is to be introduced whose dielectric constant can be found from the equation (1).

$$\varepsilon_{ML} = \sqrt{\varepsilon_r \times \varepsilon_{Air}} \quad (1)$$

This equation gives a value of around 3.4058. This is why, a material is so chosen whose dielectric constant is 3.41 i.e. Polyflon Cuflon.

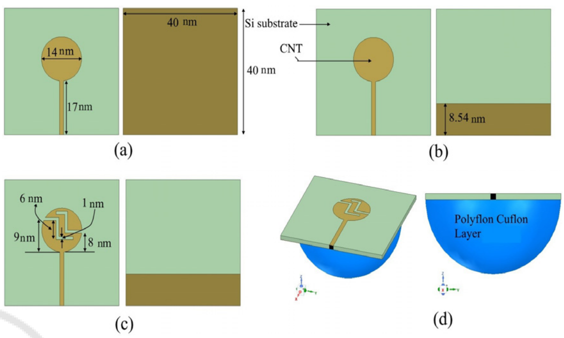

Figure 1: Antenna designs in different steps: Top view and Bottom view in (a) step-1, (b) step-2, (c) step-3, (d) step-4 (optimized).

3 RESULTS

3.1 S-Parameter

The S(1,1) parameter is studied to determine the return loss. It is significant to obtain the bandwidth of the antenna. In this study, the S(1,1) parameter is discussed for all the design steps involved to get the optimized value as given in Fig. 2. In the first step, it is from 3.3 THz to 5.1 THz. In step-2, it is improved from 2.6 THz to 5.6 THz. In the next one, it provides a bandwidth of 2.4 THz to 6 THz. And finally, after the implementation of the said layer, the obtained bandwidth is from 2 THz to 6.5 THz.

3.2 Radiation Pattern

The S(1,1) parameter result has provided two resonant frequencies in the obtained band. These are 3.4 THz and 4.6 THz. The radiation pattern of these frequencies is shown in Fig. 3 and Fig. 4 respectively. It shows a pattern uniformly distributed in each direction while the phase angles are 0^0, 90^0.

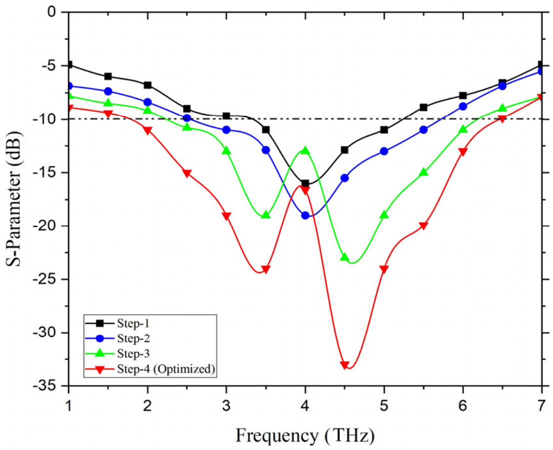

Figure 2: Reflection Co-efficient.

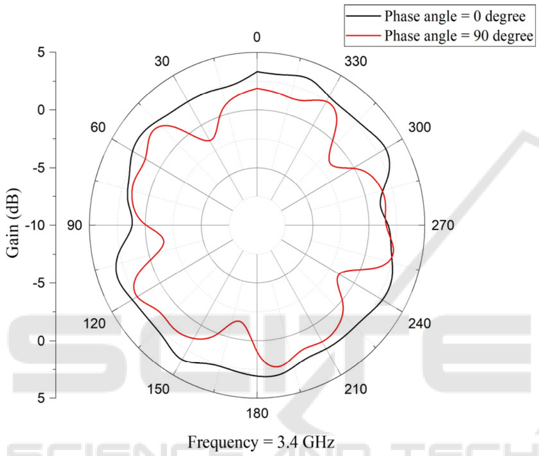

Figure 3: Radiation Pattern at 3.4 THz.

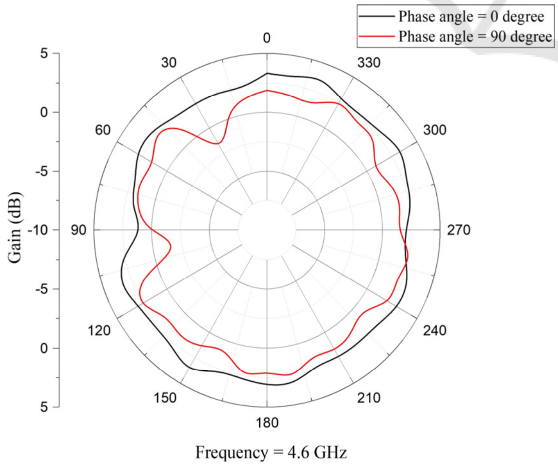

Figure 4: Radiation Pattern at4.6 THz.

3.3 Gain & Efficiency

In this section, the gain, and efficiency are studied. This section shows how the Polyflon Cuflon affects the performance of the antenna. Fig.5 and Fig.6 show the gain and efficiency of the proposed antenna respectively. These show that without the attached layer, the maximum gain is 3.5 dB while the attachment of the layer increases it up to 6.1 dB. The Radiation efficiency is also improved from 62% to 81% by implementing the attachment.

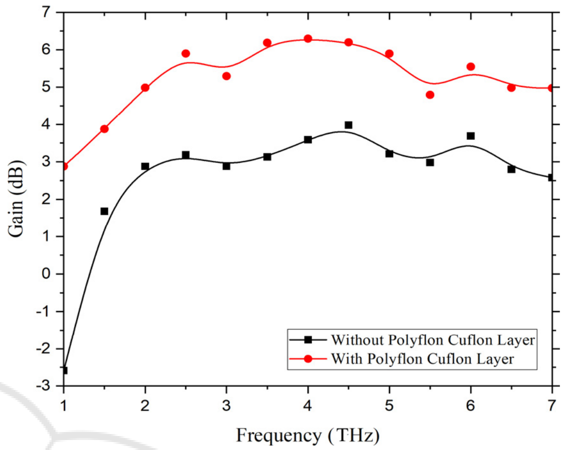

Figure 5: Gain of the proposed nano-antenna.

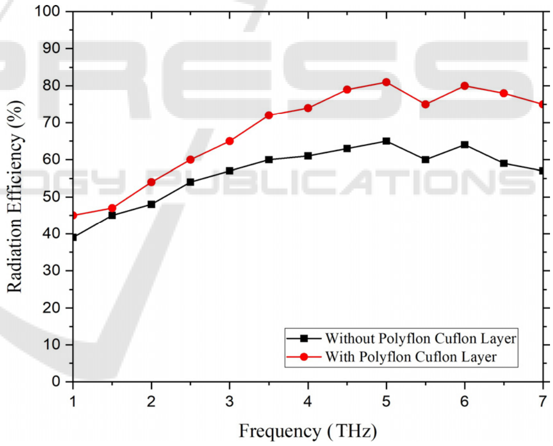

Figure 6: Radiation Efficiency of the proposed nano-antenna.

4 COMPARISON

The proposed work is compared with recent literature in Table 1.

Table 1: Table of Performance Evaluation.

References	Dimension (nm^3)	B/W (THz)	Max. Eff. (%)
Alazemi, 2016	46×24×0.432	0.4	NP
Yu, 2020	10×6.7×1.5	0.3	99.5
Dash, 2020	NP	1	93.7
Wahyudi, 2017	6×6×0.3	0.3	90
Jyothi, 2016	1.2×1.2×0.625	2	75
Li, 2016	NP	1	90
TW	**40×40×1.6**	**4.5**	**82**

5 CONCLUSION

The design of the antenna is elaborated in steps in this paper. The compact size of the antenna is one of the significant parts of this work. The bandwidth achieved is 4.5 THz (2 to 6.5 THz) with a maximum efficiency is 82% and a maximum gain is about 6.1 dB. This antenna covers the full band of the optical frequency. The performance improvement is also studied using a matching layer (Polyflon Cuflon). It shows a new way to improve the antenna performance.

Advancements in fabrication techniques promise to revolutionise multiple technological sectors through the development of nanoantennas. These techniques will allow for precise control over dimensions and materials, consequently enhancing performance and efficiency. Nano antennas hold potential across a spectrum of applications including communication technologies, sensing, imaging, and energy harvesting. Breakthroughs in terahertz technology and meta-material development are anticipated, further amplifying their impact. Ongoing research and innovation in this field are poised to unlock transformative applications in electronics, telecommunications, and beyond.

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