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- **Publication Internationale classe A**

  - Moulfi, Bouchra, Souheyla Ferouani, and Djalal Ziani Kerarti. "Optical nano patch antenna for terahertz applications with graphene." Revista Mexicana de Física 69.6 Nov-Dec (2023): 061302-1. doi https://doi.org/10.3 1349/RevMexFis.69. 061302.

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  - Moulfi Bouchra, et al. "Wide Band Nano Circular Graphene Printed Antenna for Terahertz Transmission with DGs." Telecommunications and Radio Engineering 81.2 (2022).doi 10.1615/TelecomRad Eng.2022042936.

  - Bouchra Moulfi, Souheyla Ferouani, and Ziani Kerarti Djalal. "Design of Optical Gold Printed Antenna in Terahertz Band for ON Body WBAN Applications." Microwave Review 28.1 (2022). doi http://www.mtt ser bia.org.rs/files/MWR /MWR 2022jul/Vol2 8No1-2243-2- Bouchra.pdf

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Publication class A

Optical nano patch antenna for terahertz applications with graphene

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Nano optical crescent patch antenna for Terahertz applications using Graphene is designed in this paper. The antenna is designed at 7.28 THZ with several substrates material as PTFE ($\epsilon r = 2.1$), polymide ($\epsilon r = 3.5$), RO3003 ($\epsilon r = 3$), RO4003 ($\epsilon r = 3.4$) and Arlon AD ($\epsilon r = 2.5$). Graphene is the material patch used with different properties such as chemical potential $\mu c = 0.2$ eV, relaxation time $\tau = 1$ ps and thickness of 60 nm to achieve a high gain and bandwidth. We obtained a very good performance of crescent antenna at 7.28 THZ with -37.962 dB, 7.124 dBi, 1.767 THZ of return loss, gain and bandwidth respectively which is very satisfactory for terahertz transmission between [0.1-10] THZ.

Keywords: Optical antenna; Graphene properties; return loss; radiation pattern; substrate; terahertz band; optical transmission.

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1. Introduction

Graphene has become a highly researched and used material due to its impressive properties. Scientific interest in this materiel has grown considerably since its first isolation in 2004 and continues to do so, it has many outstanding properties including electronic, optical, electrical thermal and mechanical [1].

Graphene has very high electron mobility (2×10^5 cm^2/Vs) [2], making it the most highly conductive material at room temperature, witch a conductivity of 160 S/m and a sheet resistance of 31 ohm/sq that make it a potential to overcome some draw band in new technologies, especially at band, making it able to support plasmon polariton waves which makes it of great interest to use for microstrip antenna applications. Terahertz band is located between infrared wave and microwave [3], it has a lower energies so that it is non ionizing and do not damage the samples.

The terahertz wavelength is much smaller than that of millimeter wave microwaves [4]. Therefore it has broadband advantages which carry hope to increase data transmission rate. However, it faces many challenges: As the resonance frequency is higher, the antenna size is smaller, in this case the radiation efficiency is considerably reduced and the macro-molecular absorption increases strongly. The second challenge is the lack of suitable substrate materials for this band, the substrate materials for the millimeter band cannot be used at the resonant frequency of the THz microstrip antennas and the manufacture of the terahertz antenna requires microscopic equipment for realization. These challenges arise from the fact that the THz frequency is higher than the millimeter wave frequency and the size of the corresponding antenna is much smaller than that of the millimeter wave antennas [5].

Several works have been conducted in the terahertz band including Graphene properties such as that of Moulfi *et al*., where design a circular terahertz antenna based on Graphene and use the DGS technique to extend the bandwidth, performing a parametric study on Graphene [6], Khan *et al*., designed a circular terahertz patch antenna and made one with different shapes of substrate and materials [2]. Abohmra *et al*., made a study on the characteristics of Graphene at terahertz band in a rectangular antenna for Wearable application [7]. Fakharian proposed a graphene-based multi-functional terahertz antenna [8]. Badr and Moradi proposed a new shape of the hexagonal antenna dual band the 2.14 THz and 5.41 THZ frequencies [9]. Nissiyah and Madhan did a search on Graphene based patch antenna for triple and quad band act at terahertz frequencies [10].

In this paper, we designed an optical nano crescent patch antenna for terahertz transmission using Graphene material for patch and ground plan with $t = 0.6$ μm properties. Several material substrate such as PTFE ($\epsilon r = 2.1$), polymide ($\epsilon r = 3.5$), RO3003 ($\epsilon r = 3$), RO4003 (ϵr = 3.4) and arlon AD ($\epsilon r = 2.5$) have been integrated to get a good performance of the antenna. The substrates used are based on graphene and have unique electrical and optical properties. They are very heat resistant, very flexible and inexpensive. These substrates are obtained by mixing graphene with a solution of the used substrate, namely PTFE, polymide, RO3003, RO4003 and Arlon, after which this solution is deposited on the substrates to dry it. In this way, their electrical and thermal properties are improved for use in the terahertz band [11].

The change in Graphene properties, especially in chemical potential achieve a high gain and bandwidth, which is very satisfying for terahertz transmission.

2. Crescent antenna design

We designed a nano crescent microstrip antenna using the CST software. It is fed by microstrip line with 50 ohm of impedance. Graphene is the materiel used for the radiation element called the patch and for the ground plan (Fig. 1). We used different type of materiel substrate as PTFE ($\epsilon r = 2.1$), polymide ($\epsilon r = 3.5$), RO3003 ($\epsilon r = 3$), RO4003 ($\epsilon r = 3.4$) and arlon AD ($\epsilon r = 2.5$) with thickness $h = 2.798$ μm.

The fabrication of a micrometer-thick substrate requires a complex manufacturing process. Here are some general steps for the fabrication of such a substrate: The process of fabricating a micrometer graphene-based substrate for terahertz applications is complex and relies on several steps [12–14]:

Choosing the appropriate substrate material: This step takes into account the properties of the substrate material as well as the properties of the substrate itself: thermal resistance, mechanical stability and electrical conductivity required.

Preparation of the substrate material: The material must be thoroughly cleaned to remove all kinds of impurities, dust and other contaminants.

Thin film deposition: A thin film made by chemical vapor deposition is deposited on the substrate to be bonded to the graphene.

Preparation of graphene: Graphene can be prepared using several techniques such as: chemical vapor deposition (CVD), epitaxial growth, or mechanical exfoliation.

Graphene deposition: Graphene must be deposited on the substrate by dry transfer or by wet transfer. It should be noted that the fabrication phase of graphene thin film substrates is very sensitive and an expert in the field of manufacturing should be consulted.

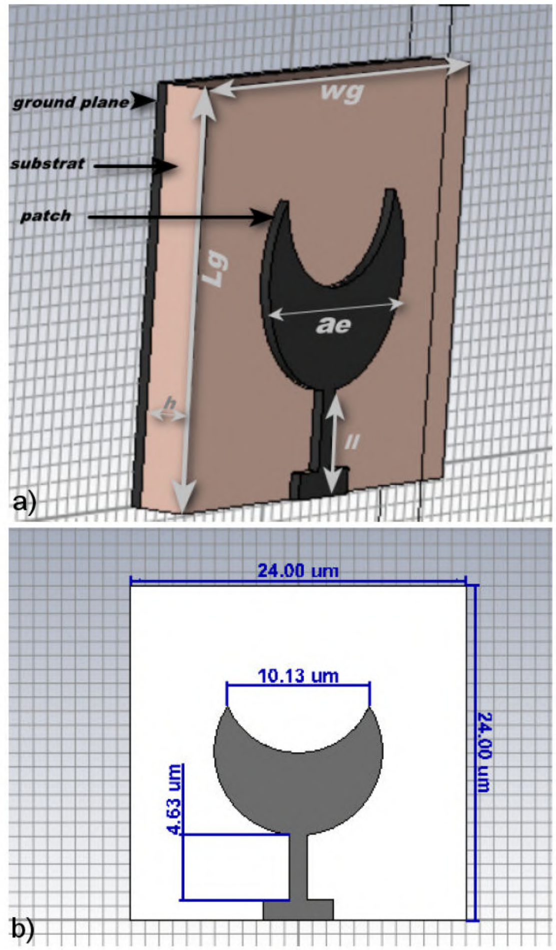

FIGURE 1. The Crescent Proposed Graphene patch antenna, a) antenna design, b) antenna dimensions.

The patch antenna dimensions are calculated from the equations below [15]:

$$ae = a\sqrt{1 + \frac{2h}{\pi \epsilon a}\ln\left(\frac{\pi a}{2h}\right) + 1.7726}, \quad (1)$$

where

$$a = \frac{F}{\sqrt{1 + \frac{2h}{\pi \epsilon_r F}[\ln\left(\frac{\pi F}{2h}\right) + 1.7726]}}, \quad (2)$$

and

$$F = \frac{(8.791 * 10^9)}{fr\sqrt{\epsilon r}}, \quad (3)$$

$$ll = L - 2\delta L, \quad (4)$$

where

$$\frac{\delta L}{h} = 0.412\frac{(\epsilon_{\text{eff}} + 0.3)(\frac{w}{h} + 0.264)}{(\epsilon_{\text{eff}} - 0.258)(\frac{w}{h} + 0.8)}, \quad (5)$$

$$Lg = ll + 2ae + 6h, \quad (6)$$

$$Wg = 2ae + 6h, \quad (7)$$

with ae the radius of the crescent patch; Lg the length of both substrate and ground plane; Wg the width of both substrate and ground plane; h the substrate thickness; fr the resonant frequency; ϵ_r the dielectric constant; and ll the length of the line.

Graphene is a two-dimensional material consisting of a single layer of carbon atoms in the form of a honeycomb lattice. The graphene layer is made by a technique called chemical vapor deposition (CVD). It consists in depositing a thin layer of graphene on a substrate by means of a chemical reaction. To produce high quality graphene with desired properties, it is necessary to carefully control the chemical potential by adjusting the temperature, gas pressure and other factors in the CVD process [4,5].

3. Dispersion relation of graphene

Graphene is considered as an excellent material because of its surface plasmon polarization propagation (SPP) [17].

The SPP wavelength is generally represented as a function of frequency, so in the terahertz frequency range the SPP wavelength is of the order of a few micrometers, corresponding to the size of the nanometer antenna and the wavelength is relatively small. In effect the propagation length of a graphene based antenna is less than the wavelength [18].

The SPP dispersion of Graphene relation in the field of effective index can be presented as [19]

$$\sqrt{\eta^2-\eta_{\text{eff}}^2}+\eta^2\sqrt{\eta^2-\eta_{\text{eff}}^2}+\frac{4\pi}{c}\sigma\sqrt{1-\eta_{\text{eff}}^2}\sqrt{\eta^2-\eta_{\text{eff}}^2}=0, \tag{8}$$

where η is the refractive index, σ is the conductivity of Graphene and c is the speed of light, and η_{eff} the complex effective index

$$\eta_{\text{eff}}=\sqrt{1-4\frac{\mu_0}{\epsilon_0}\frac{1}{\sigma^2}}. \tag{9}$$

The dispersion relation can be also presented in terms of k_{spp} as [17]

$$\frac{1}{\sqrt{K_{\text{spp}}^2-\frac{w^2}{c^2}}}+\frac{\epsilon}{\sqrt{K_{\text{spp}}^2-\frac{w^2}{c^2}\epsilon}}=-j\frac{\sigma}{w\epsilon o}, \tag{10}$$

where r is the dielectric constant of the substrate material and the effective index K_{spp} (surface plasmons wave vector) varies with the dielectric material metal interface and ω is the angular frequency of the waves: ($\omega=kc$)

$$K_{\text{spp}}=\epsilon_0\frac{1+\epsilon r}{2}\frac{2iw}{\sigma}. \tag{11}$$

4. Graphene conductivity

Graphene has two-dimensional single layer design in which carbon atoms are provided in the form of infinite honeycombs. Graphene conductivity formula is given by the Kubo formula [8]:

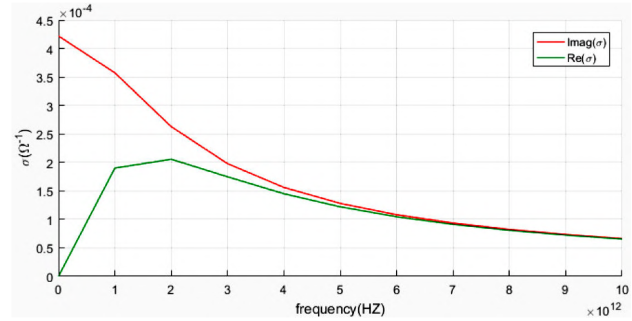

FIGURE 2. Graphene conductivity curve with properties μc= 0 eV and $\tau=0.1$ ps at $T=300$ K [1].

$$\sigma\text{inter}=\frac{e^2}{4h}H\left(\frac{w}{2}\right)+4\frac{wj}{\pi}\int_0^\infty\frac{H(w)-H(\frac{w}{2})}{w^2-4\epsilon^2}\delta\epsilon, \tag{12}$$

$$H(\epsilon)=\frac{\sinh\left(\frac{h\epsilon}{KT}\right)}{\cosh\left(\frac{\mu c}{KT}\right)}\cosh\left(\frac{h\epsilon}{KT}\right), \tag{13}$$

$$\sigma\text{intra}=\frac{2kTq^2j}{h(T^{-}1hj+wh)}2\ln\left(\cosh\frac{\mu}{2TK}\right), \tag{14}$$

$$\sigma s=\sigma\text{intra}+\sigma\text{inter}, \tag{15}$$

where σs the surface conductivity, consists of two terms σinter: the interband conductivity and σintra:the intraband conductivity.

At terahertz frequencies we have room temperature, and generally $hw\ll 2\,\mu c$ in this case we have either in the ohmic domain or in the plasmonic domain, and inter-band (σintra) transitions can be neglected.

Moreover, the condition $\mu c\gg kBT$ is generally very small, allowing a low temperature approximation. Thus, the final approximate formula is

$$\sigma s=\frac{2kTq^2j}{h(T^{-}1hj+wh)}2\text{in}\cosh\frac{\mu}{2TK}. \tag{16}$$

The chemical potential and the relaxation time of Graphene as well as the total conductivity are changed due to chemical doping or electrostatic polarization, which results in the modification of the resonance characteristics of Graphene. Figure 2 represents the real and imaginary part of Graphene conductivity for μc = 0 eV and $\tau=0.1$ ps at $T=300$ K. Figure 3 represents Graphene conductivity variation with respect to chemical potential (μc) for $\tau=0.1$ ps at $T=300$ K and Fig. 4 represents Graphene conductivity curve variation with respect to relaxation time (τ) for $\mu c=0$ eV at $T=300$ K. The antenna uses surface-plasmon polariton wave propagation in Graphene at the terahertz frequency

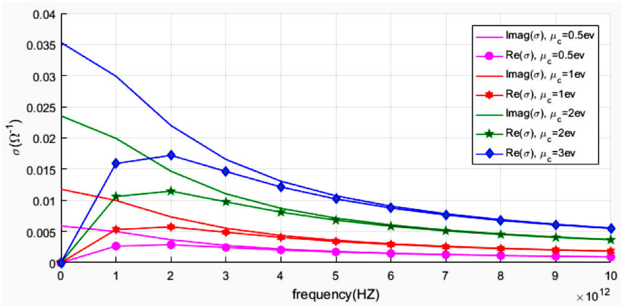

FIGURE 3. Graphene conductivity curve variation with respect to chemical potential (μc) for $\tau = 0.1$ ps at $T = 300$ K [1].

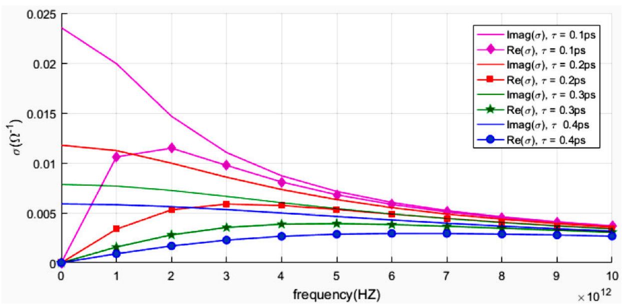

FIGURE 4. Graphene conductivity curve variation with respect to relaxation time (τ) for $\mu c = 0$ eV at $T = 300$ K [1].

band. Simulation results demonstrate the conductivity of Graphene and structured has the potential to be used as a tunable terahertz antenna.

5. Choice of substrate

In this part we simulated the crescent patch antenna with several type of substrates as PTFE ($\epsilon r = 2.1$), polymide ($\epsilon r = 3.5$), RO3003 ($\epsilon r = 3$), RO4003 ($\epsilon r = 3.4$) and Arlon AD ($\epsilon r = 2.5$) to evaluate performance crescent patch antenna. The antenna parameters are calculated using Eqs. (1-7); we used Graphene material for the patch and ground plane with the following characteristics: temperature $T = 300$ K, chemical potential $\mu c = 2$ eV, relaxation time $\tau = 1$ ps and thickness of 60 nm.

A graphene layer with a chemical potential of 2 eV is ensured for a thickness of 60 nm using a technique called "adsorption doping", which consists in intentionally introducing impurities into the graphene layer to adjust its electrical properties. The doping concentration required to reach a chemical potential of 2 eV depends on the specific type of dopant used, the temperature and the duration of the doping process. Experimental optimization is very necessary to reach the desired doping concentration. Once the desired doping concentration is reached, the graphene layer can be characterized using techniques such as Raman spectroscopy to confirm the existence of the desired electronic properties [6,7].

Figure 5 summarizes the simulation results of reflection coefficient and Fig. 7 represent the polar radiation pattern of crescent antenna with different types of substrate.

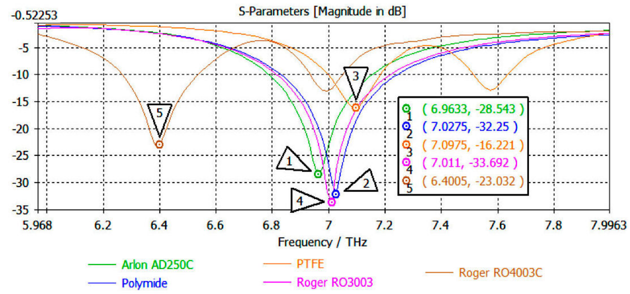

FIGURE 5. Reflection coefficient parameter $S11$.

As shown in Fig. 5, we obtained a very good return loss of -28.592 dB at 6.9615 Thz frequency and 350.63 GHZ of bandwidth, by using Arlan AD 250 C material substrate.

There are several applications in the terahertz band and especially the 7 THZ frequency such as:

- **Medical imaging:** The 7 THZ band is used for imaging applications such as security control and medical imaging. Terahertz waves pass through clothing and skin.
- **Spectroscopy:** The 7 THz band is useful for spectroscopy applications. These applications could be used in fields such as materials science, chemistry and biology.
- **Wireless communication:** The 7 THz band offers the possibility of broadband wireless communication for applications such as virtual reality, high-definition video streaming, and ultra-fast data transfer.

The frequency of 7 THz corresponds to a wavelength of 42.8 micrometers, which is in the far infrared region of the optical band. This frequency is generated using high power laser sources, which are capable of producing very short optical pulses with high repetition rates. Two infrared diode lasers with neighboring wavelengths are used and combined in a tellurium crystal to produce an electromagnetic wave with a wavelength of 42.8 micrometers.

The detection of the frequency of 7 THz presents a great technical challenge since it is located in the region of terahertz waves. The photoconductive detection is the most com-

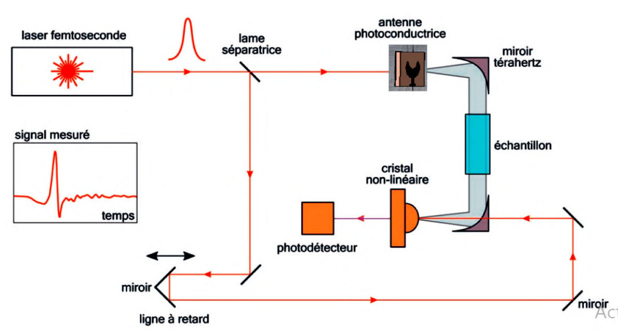

FIGURE 6. The detection of the frequency of 7 THz with proposed antenna [22].

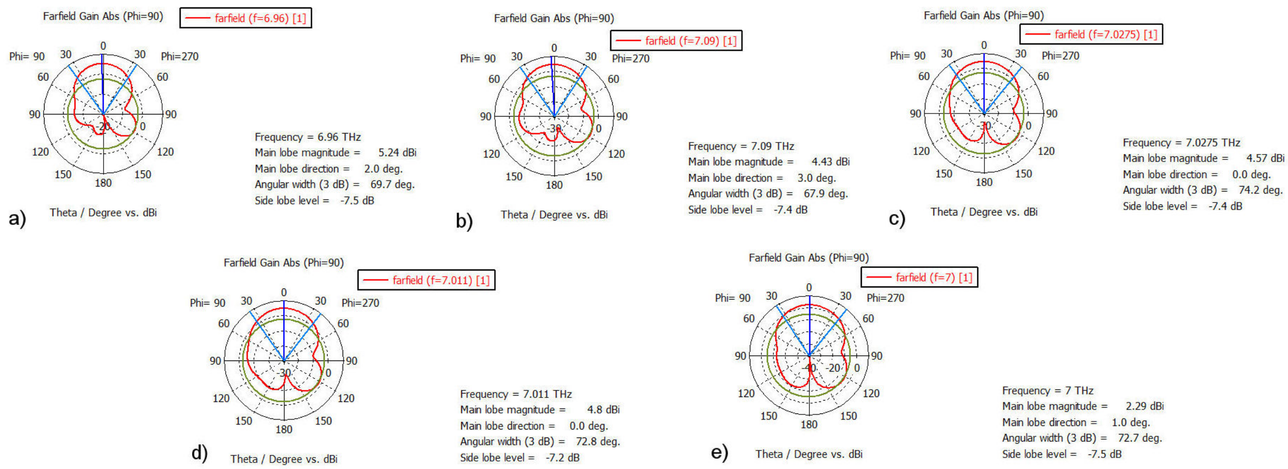

FIGURE 7. Polar gain with a) arlan AD 250C ($\epsilon r = 2.5$) b) teflon ($\epsilon r = 2.1$) c) polymide ($\epsilon r = 3.5$) d) RO3003 ($\epsilon r = 3$) e) RO4003 ($\epsilon r = 3.4$).

TABLE I. Results comparison.

The substrat	Frequency [THZ]	$S11$ (dB)	Gain (dBi)	VSWR	BP (GHZ)
Arlan AD 250C ($\epsilon r = 2.5$)	6.9615	-28.592	5.24	1.07	350.63
Teflon ($\epsilon r = 2.1$)	7.0935	-16.323	4.417	1.36	168.52
Polymide ($\epsilon r = 3.5$)	7.0275	-32.25	4.568	1.05	418.99
RO3003 ($\epsilon r = 3$)	7.011	-33.692	4.803	1.04	441.77
RO4003C ($\epsilon r = 3.4$)	6.9945	-13.152	2.287	1.57	124.11

mon technique for the detection of these waves, it consists in using a photoconductive material like gallium arsenide (GaAs) which is sensitive to terahertz frequencies. When a terahertz wave beam is directed onto the material, it generates electrons and holes that can be detected using an electrode connected to the material. The displacement of the mirror allows to adjust the delay while allowing to measure the phase and the amplitude of the signal [8, 9].

Figure 7 shows the 3D polar radiation pattern of crescent antenna at all frequencies obtained with the use of several material substrates. The radiation pattern obtained is unidirectional. Table I resumes all simulations results obtained with severals substrate materials and Graphene properties mentioned above.

6. Graphene chemical potential variation

The objective of our work is to design a graphene-based patch antenna for the terahertz band with the best characteristics. According to our results, all the substrates used show good performance in terms of $S11$, gain and bandwidth. The Arlan substrate shows a higher gain of 5.28 dB, hence we will use it to further improve the performance of the designed patch antenna in the terahertz band. We simulated in Fig. 8 the return loss of the proposed antenna and we varied the value of the chemical potential for gain and bandwidth enhancement.

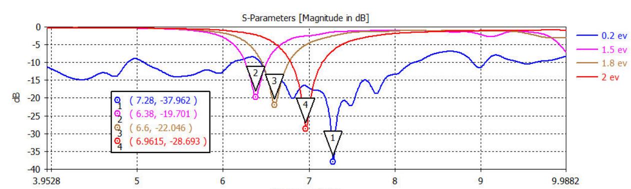

FIGURE 8. Return loss $S11$ with 0.2 eV, 1.5 eV, 1.75 eV and 3 eV of chemical potential.

As shown in Fig. 8, a high bandwidth of 1.767 THz is obtained with -37.962 dB of return loss and with 0.2 eV of chemical potential.

The polar radiation of Fig. 8 b)-d) is almost omnidirectional for 1.5, 1.8, 2 eV of chemical potential values. The best performances are obtained with 0.2 eV in wich the polar radiation pattern is omnidirectional with angular wide of 63.2 deg and gain of 7.13 dBi.

TABLE II. Simulations Results.

Chem-Potential (eV)	Fr (THZ)	$S11$ (DB)	GAIN (dBi)	BP (GHZ)
2	6.9615	-28.592	5.24	350.63
1.8	6.6	-22.046	4.55	322.18
1.5	6.38	-19.701	4,573	252.29
0.2	7.28	-37.962	7.134	1767.3

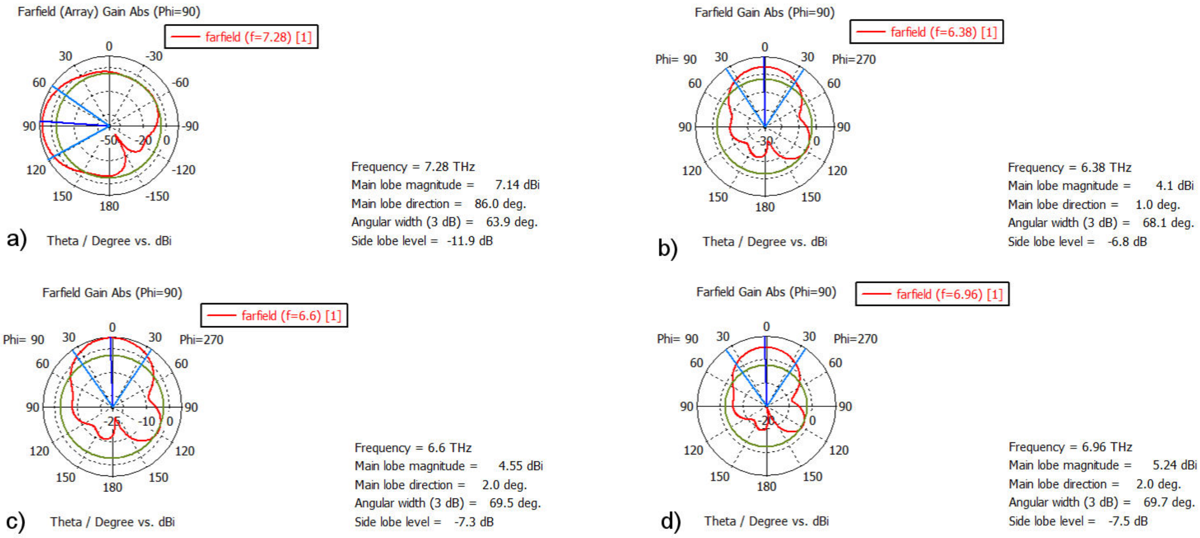

FIGURE 9. 3D Gain a) with chemical potential 0.2 eV, b) with chemical potential 1.5 eV, c) with chemical potential 1.8 eV, d) with chemical potential 2 eV.

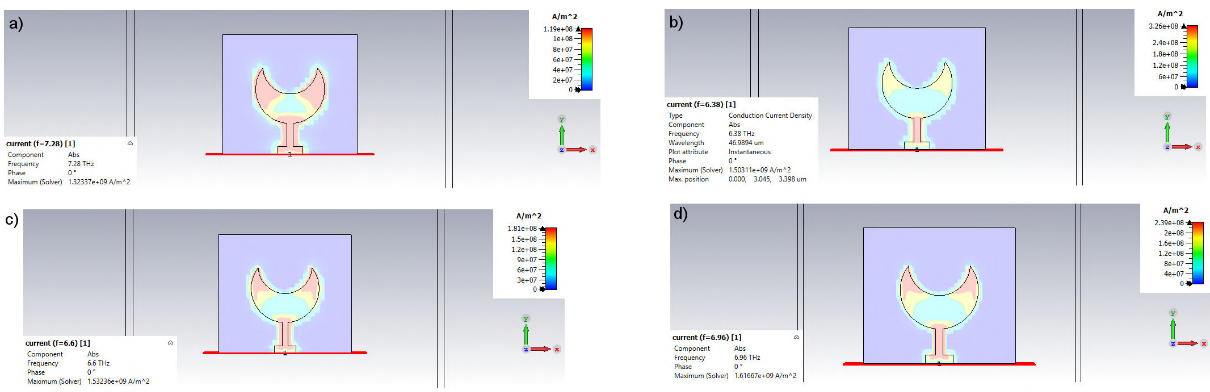

FIGURE 10. Current density a) with chemical potential 0.2 eV, b) with chemical potential 1.5 eV, c) with chemical potential 1.8 eV (d)with chemical potential 2 eV.

TABLE III. Comparison of proposed work with previous research.

	Fr (THZ)	$S11$ (DB)	GAIN (dBi)
Proposed antenna	7.28	-37.962	7.134
[6]	3.26	-30.706	3.437
	4.69	-55.54	5.008
	5.64	-37.434	5.233
	6.95	-26.812	6.62
[24]	$0.434 - 1.684$	-39	5.72
[25]	4.104	-40	3.8
[26]	2.9	-28.39	6.48

Obtained a high gain of 7.13 dB with 0.2 eV which is very satisfactory in terahertz transmission.

Figure 10 shows the current density of the proposed crescent antenna for 0.2, 1.5, 1.8 and 2 eV of Graphene chemical potential. The majority of the current density is concentrated in the left and right ends of the patch antenna.

To value our work, we compared in Table III the simulations results obtained with other previous and recent literature.

As shows in Table III, the proposed crescent patch antenna gives a high gain of 7.13 dBi and bandwidth of 1.769 Thz compared to all references cited.

7. Antenna fabrication

Fabrication and characterization of a graphene based patch antenna is a complex process, requiring a very high level of expertise in this field hence consultation with experts in this field or professional assistance for fabrication and characterization of the patch antenna is highly recommended.

Once the design of the antenna is optimized, the proposed patch antenna can be fabricated and characterized as follows [27, 28]:

Preparation of the substrate material: The material must be thoroughly cleaned to remove all kinds of impurities, dust and other contaminants.

Thin film deposition: A thin film made by chemical vapor deposition is deposited on the substrate to be bonded to the graphene.

Preparation of graphene: Graphene material can be prepared using several techniques such as: chemical vapor deposition (CVD), epitaxial growth, or mechanical exfoliation.

The chemical Vapor Deposition (CVD) involves growing a thin layer of graphene on a metal substrate by adding a hydrocarbon gas, such as methane or ethylene, in a high-temperature furnace. Then, the carbon atoms in the gas are deposited on the metal substrate, creating a graphene layer.

Graphene deposition: Graphene must be deposited on the substrate by dry transfer or by wet transfer.

Patch antenna fabrication: it consists on using standard photolithography techniques such as spin coating, mask alignment and etching.

Patch antenna characterization: in this step, we can use network analyzer, far-field radiation pattern measurement, and impedance measurement for proposed patch antenna characterization.

8. Conclusion

The Terahertz band is envionned for serveral application such as WBAN, 6G, 5G, teledetection etc.

In this paper a high gain and bandwidth optical crescent antenna has been designed to be used in Terahertz applications from 0.1 to 10 THz . The nano patch antenna is analysed and simulated using Graphene for the patch and several material substrates such as PTFE($\epsilon r = 2.1$), Polymide ($\epsilon r = 3.5$), RO3003 ($\epsilon r = 3$), RO4003 ($\epsilon r = 3.4$) and Arlon AD ($\epsilon r = 2.5$). We obtained a very good performance with a Graphene chemical potential of 0.2 eV and Arlon AD ($\epsilon r = 2.5$) material substrate. The results obtained are very satisfactory and the proposed crescent antenna can be used in several terahertz band applications.

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WIDE BAND NANO CIRCULAR GRAPHENE PRINTED ANTENNA FOR TERAHERTZ TRANSMISSION WITH DGS

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A nano circular graphene printed antenna for terahertz transmission has been designed in this paper. Graphene is the material used for the patch with 60 nm of thickness and 0.2 eV of relaxation time. Several material substrates such as PTFE (ε_r = 2.1), polyimide (ε_r = 3.5), RO3003 (ε_r = 3), RO4003 (ε_r = 3.4), and Arlon AD (ε_r = 2.5) have been used to evaluate performances of the proposed nano printed antenna. Rogers 4003C substrate gives better performance compared to the other substrates used. The nano antenna operates at the frequencies of 3.26, 4.69, 5.64, and 6.95 THz with −30.7, −55,54, −37.434, and −26.812 dB of reflection coefficient, respectively. The gain is greater than 5 dB and the bandwidth obtained is more than 4 THz for all frequencies obtained, which is very satisfactory. Defected ground structure (DGS) technique was used. The proposed nano circular patch antenna can be used for several applications in terahertz transmissions such as optical transmission, new 5G/6G with high data traffic, etc.

KEY WORDS: *graphene antenna, patch antenna, S11, radiation pattern, substrate, terahertz transmission, optical transmission*

1. INTRODUCTION

Over the last few years, as the transmission has developed, the THz or optical band situated between the infrared and the microwave frequency has become very important due to the current increase in data transmission (He et al., 2020), the birth of new technologies such as 5G and 6G which will surpass Gbits per second (Gbit/s) with high data traffic, we cannot manage it with the microwave connection (Nissanov et al., 2021), and wireless body area network (WBAN) applications that require real-time response (Das and Rawat, 2021; Mahmood et al., 2021). This is why several studies have been carried out on the terahertz band (0.1–10) THz which provided the best performance for the antenna in terms of gain, bandwidth, directivity, reflection coefficient, etc., such as the photoconductive antenna (PSA) (Peytavit et al., 2009), the horn antenna THz (Wu et al., 2012; Peytavit et al., 2008), lens antennas (Faridani and Khatir, 2018), and microstrip antennas (Türker et al., 2006).

To further develop the performance of these nano-antennas, the new material which has an excellent properties of the plasmon surface materials (the graphene) has been integrated. This type of material has a very high electrical and thermal conductivity (> 5,000 $Wm^{-1}K^{-1}$) at the terahertz band, much higher than other old material used for antennas, and a high electron mobility (> 1,00,000 $cm^2V^{-1}s^{-1}$) with a resistance of > 130 GPa, it is considered an ideal material for terahertz antennas (Varshney et al., 2020). Several studies have been conducted on the characteristics of graphene in the optical band (Nosrati et al., 2021; Llatser et al., 2012) and on graphene-based terahertz patch antennas (Tewari and Saini, 2002; Bala and Marwaha, 2016; Khan et al., 2020; Bouchra et al., 2022) such as reconfigurable graphene-based antennas (Moradi et al., 2021; Kiani et al., 2021), MIMO graphene-based antennas (Xu et al., 2014; Han et al., 2018), and 6G graphene-based antennas (Hajiyat et al., 2021).

In this paper, we designed with the help of CST microwave software a new nano circular patch antenna using graphene as a material of the patch with the use of different type of dielectric substrates such as PTFE (ε_r = 2.1), polyimide (ε_r = 3.5), RO3003 (ε_r = 3), RO4003 (ε_r = 3.4), and Arlon AD (ε_r = 2.5). The chosen thickness of the substrate is 2.798 μm and the parameters of graphene used are relaxation time 1 ps, temperature 300 K, and thickness 60 nm. The chemical potential values changed between 0.2, 0.8, 1.6, and 1.8 eV. To ameliorate the performance of the proposed antenna, defected ground structure (DGS) has been integrated to improve the bandwidth of the proposed antenna for optical transmissions (Breed, 2008; Guha et al., 2014). The simulation results are demonstrated in the sections below.

2. CIRCULAR PATCH ANTENNA DESIGN

We designed a nano circular patch antenna using graphene (Fig. 1) with the following characteristics: thickness 0.6 nm, chemical potential μc = 2 eV, relaxation time τ = 1 ps, and temperature T = 300 K. The antenna is fed by a microstrip line with an impedance of 50 Ω. The substrates used are PTFE (ε_r = 2.1), polyimide (ε_r = 3.5), RO3003 (ε_r = 3), RO4003 (ε_r = 3.4), and Arlon AD (ε_r = 2.5). The dimensions of the antenna are calculated with the following equations (Kiruthika and Shanmuganantham, 2016):

$$ae = a \times \left(1 + \left(2 \times \frac{h}{3.14 \times a \times eps}\right) \times \ln\left(\frac{3.14 \times a}{2 \times h}\right) + 1.7726\right)^{0.5} \tag{1}$$

$$Lg = ll + 2 \times ae + 6 \times h \tag{2}$$

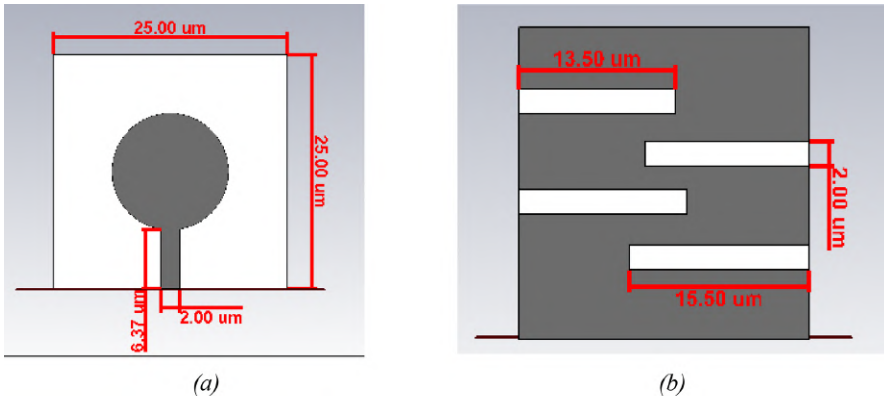


FIG. 1: (a) Front view of the circular proposed graphene patch antenna; (b) rear view of the circular proposed graphene patch antenna

$$Wg = 2 \times ae + 6 \times h \quad (3)$$

where a_e is the size of the patch, *Lg* is the length of substrate and ground plane, and *Wg* is the width of substrate and ground plane

3. SIMULATION AND RESULTS

Figure 2 shows the simulation result of the proposed antenna with different types of substrate: PTFE ($\varepsilon_r = 2.1$), polyimide ($\varepsilon_r = 3.5$), RO3003 ($\varepsilon_r = 3$), RO4003 ($\varepsilon_r = 3.4$), and Arlon AD ($\varepsilon_r = 2.5$). Table 1 summarizes all results.

As shown in Fig. 2 and Table 1, Rogers RO4003C gives better results. The return loss obtained is −65.882 dB with 2.759 dBi of gain and 2.0169 THz bandwidth at 7.39 THz frequency. For the second frequency of 5.59 THz, the return loss obtained is −25.915 dB with 2.1 dB of gain and 675.11 GHz of bandwidth.

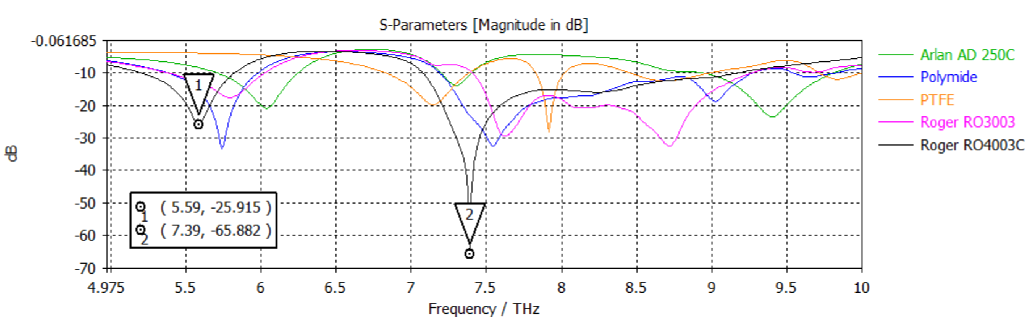


FIG. 2: Reflection coefficient parameter S11

TABLE 1: Results comparison

Substrate	Frequencies (THz)	S11 (dB)	Gain (dBi)	Bandwidth (GHz)
Arlan AD 250C	6.04	−21.082	3.932	548.2
	7.3	−13.945	3.789	206.67
	9.41	−23.602	5.075	0.852
Polyimide	5.74	−33.403	2.11	298.18
	7.55	−32.391	2.821	2118.1
PTFE	7.15	−19.91	3.34	573.8
	7.92	−28.23	3.964	232
	8.69	−12.5	2.265	573.84
Roger RO 4003C	5.59	−25.915	2.1	675.11
	7.39	−65.882	2.759	2016.9
Roger RO3003	5.79	−29.657	2.269	729.62
	8.72	−32.5	4.517	1869.2

For better performance of the antenna, we changed in Fig. 3 the values of the chemical potential of the graphene material. Figures 3 and 4 show the reflection coefficient S11 of the proposed antenna based on Rogers RO4003C substrate with chemical potential

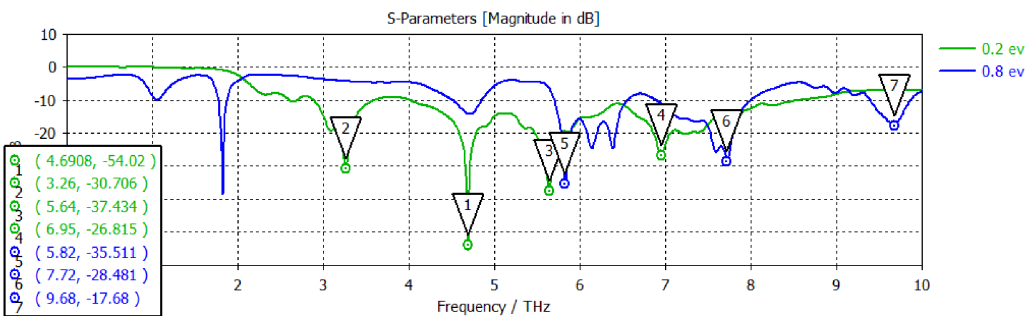


FIG. 3: S11 parameter with chemical potential values of 0.2 and 0.8 eV

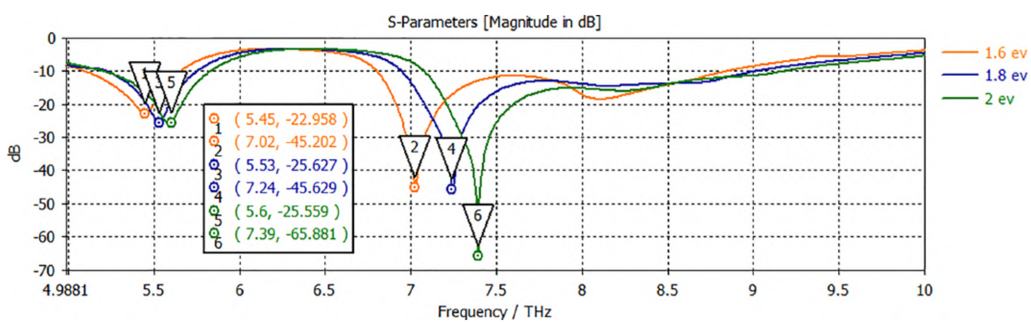
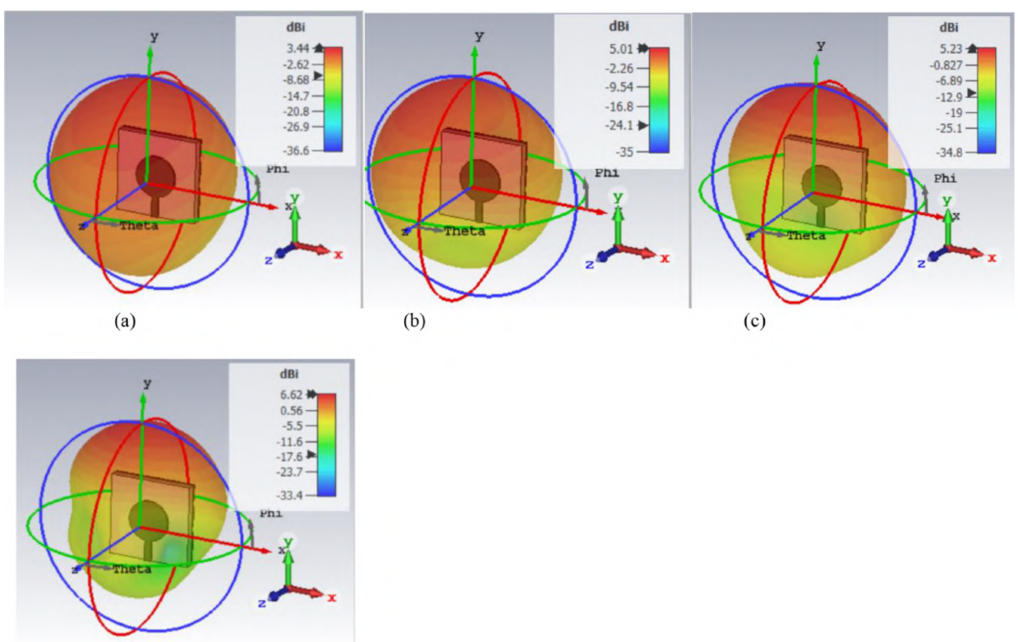


FIG. 4: S11 parameter with chemical potential values of 1.6, 1.8, and 2 eV

TABLE 2: Effect of chemical potential on return loss (S11) characteristics

Chemical potential (eV)	Frequency (THz)	S11 resonance (dB)
0.2	3.26	−30.706
	4.69	−55.54
	5.64	37.434
	6.95	−26.812
0.8	5.82	−35.511
	7.72	−28.481
	9.68	−17.68
1.6	7.02	−25.559
	5.45	−45.202
1.8	5.53	−21.573
	7.24	−45.629
2	5.6	−25.559
	7.39	−65.881



(d)

FIG. 5: (a) 3D radiation pattern of the antenna at 0.2 eV for 3.26 THz; (b) 3D radiation pattern of the antenna at 0.2 eV for f = 4.69 THz; (c) 3D radiation pattern of the antenna at 0.2 eV for f = 5.64 THz; and (d) 3D radiation pattern of the antenna at 0.2 eV for f = 6.95 THz

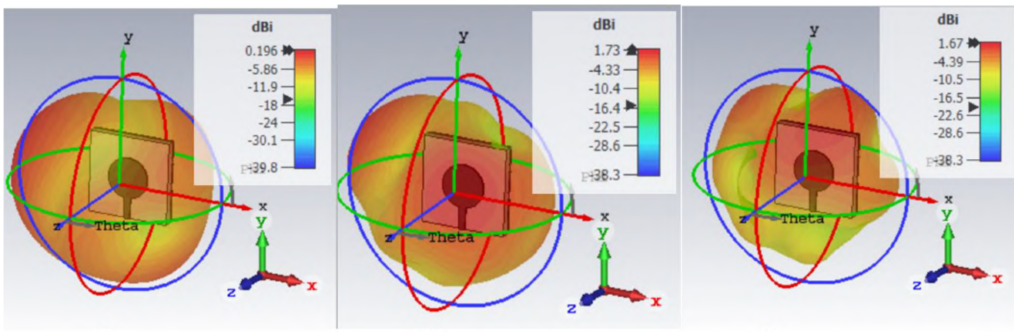


FIG. 6: (a) 3D radiation pattern of the antenna at 0.8 eV for f = 5.82 THz; (b) 3D radiation pattern of the antenna at 0.8 eV for f = 7.72 THz; and (c) 3D radiation pattern of the antenna at 0.8 eV for f = 9.68 THz

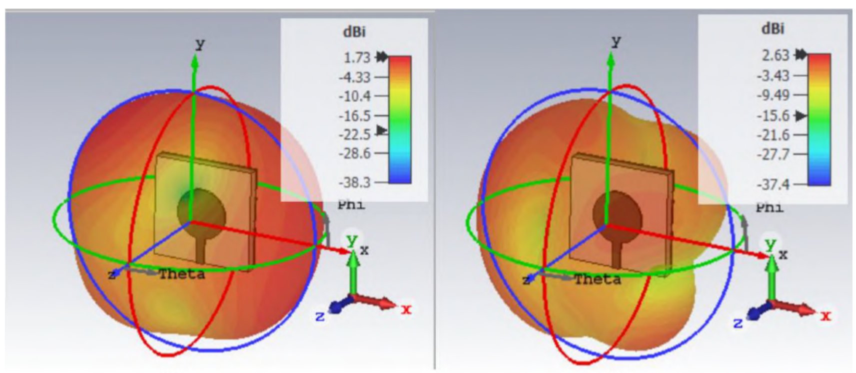


FIG. 7: (a) 3D radiation pattern of the antenna at 1.6 eV for f = 7.02 THz; and (b) 3D radiation pattern of the antenna at 1.6 eV for f = 5.4 THz

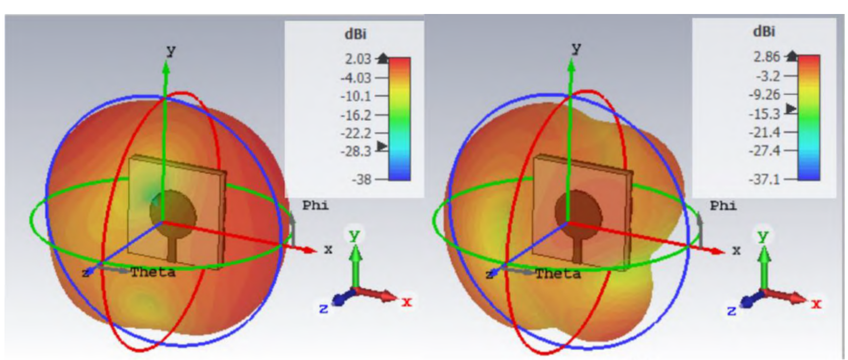


FIG. 8: (a) 3D radiation pattern of the antenna at 1.8 eV for f = 5.53 THz; and (b) 3D radiation pattern of the antenna for f = 7.24 THz

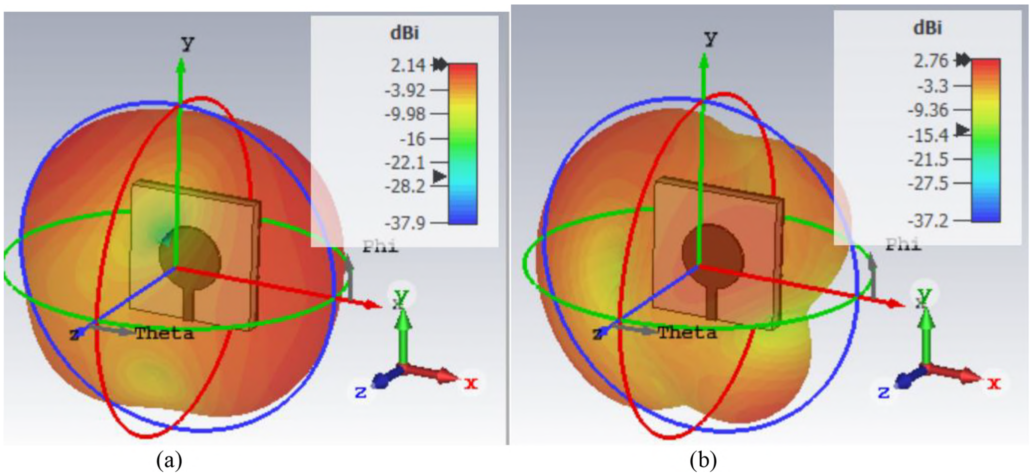


FIG. 9: (a) 3D radiation pattern of the antenna at 0.2 eV for f = 5.6 THz; and (b) 3D radiation pattern of the antenna at 0.2 eV for f = 7.39 THz

0.2, 0.8, 1.6, 1.8, and 2 eV. Simulations results are resumed in Table 2. 3D radiation pattern of the proposed graphene antenna are shown in Figs. 5–9, and polar radiation patterns of the proposed graphene antenna are show in Figs. 10–14. The gain, bandwidth, and voltage standing wave ration results of all the frequencies obtained are resumed in Table 3. As shown in Table 3, chemical potential of 0.2 eV gives better performances of gain and bandwidth which exceeds 5 dB and 4 THz, respectively.

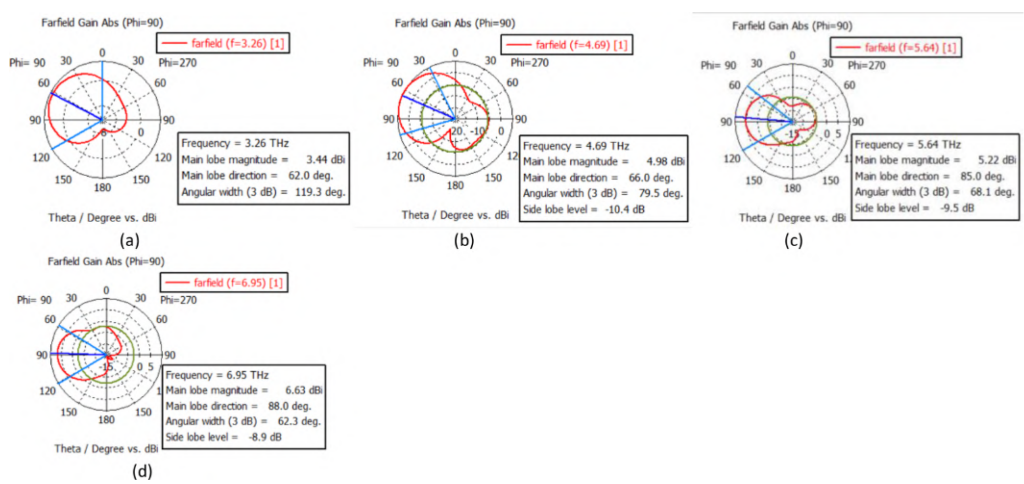


FIG. 10: (a) Polar radiation pattern of the antenna at 0.2 eV for 3.26 THz; (b) polar radiation pattern of the antenna at 0.2 eV for f = 4.69 THz; (c) polar radiation pattern of the antenna at 0.2 eV for f = 5.64 THz; (d) polar radiation pattern of the antenna at 0.2 eV for f = 6.95 THz

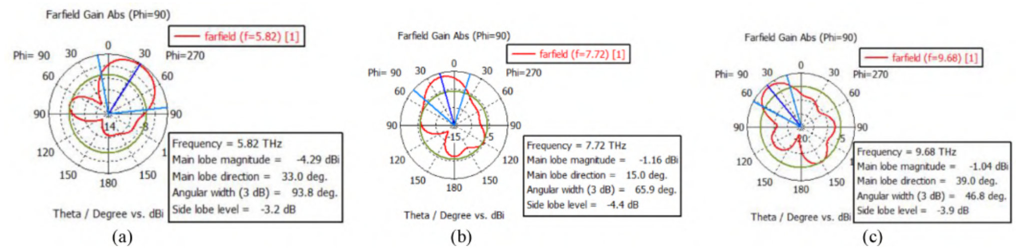


FIG. 11: (a) Polar radiation pattern of the antenna at 0.8 eV for f = 5.82 THz; (b) polar radiation pattern of the antenna at 0.8 eV for f = 7.72 THz; and (c) polar radiation pattern of the antenna at 0.8 eV for f = 9.68 THz

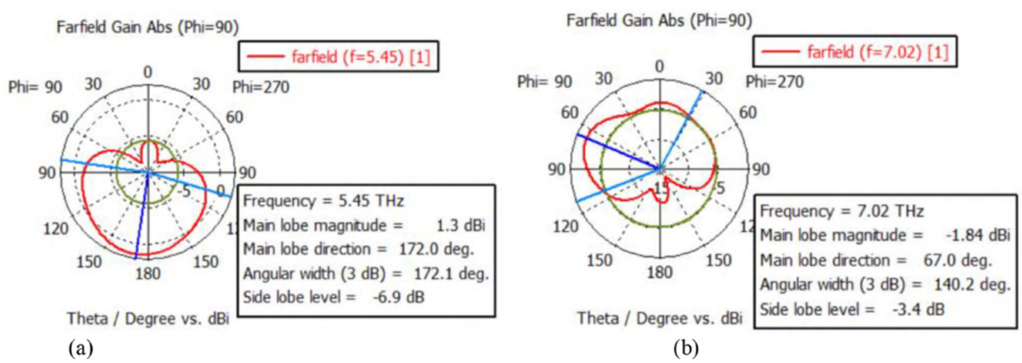


FIG. 12: (a) Polar radiation pattern of the antenna at 1.6 eV for f = 7.02 THz; and (b) polar radiation pattern of the antenna at 1.6 eV for f = 5.45 THz

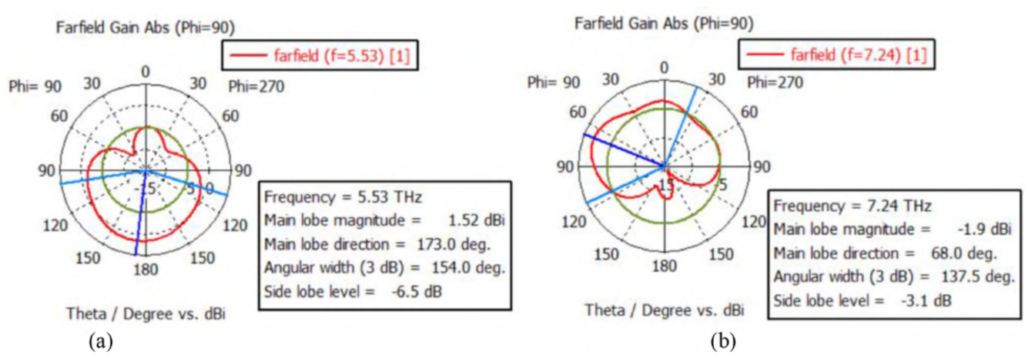


FIG. 13: (a) Polar radiation pattern of the antenna at 1.8 eV for f = 5.53 THz; and (b) polar radiation pattern of the antenna for f = 7.24 THz

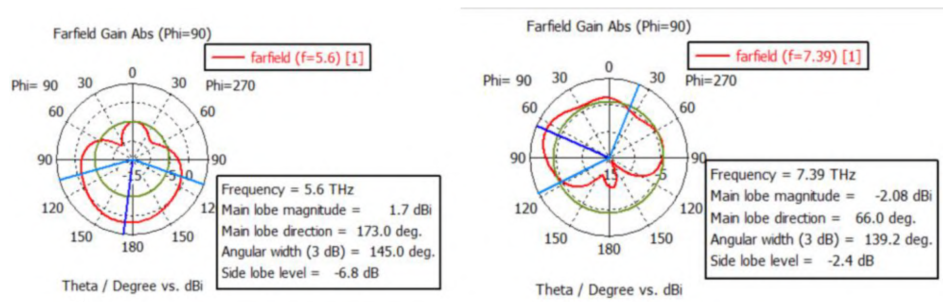


FIG. 14: (a) Polar radiation pattern of the antenna at 0.2 eV for f = 5.6 THz; and (b) polar radiation pattern of the antenna at 0.2 eV for f = 7.39 THz

TABLE 3: Simulations results

Frequency (THz)	Chemical potential (eV)	Gain (dB)	Bandwidth (GHz)	Voltage standing wave ratio (VSWR)
3.26	0.2	3.437	653.46	1.0603
4.69		5.008	4434.9	1.0034
5.64		5.233		1.0959
6.95		6.62		1.02
5.82	0.8	0.196	849.8	1.0342
7.72		1.734	1120.4	1.0783
9.68		1.66	492.97	1.3005
7.02	1.6	2.628	563.52	1.011
5.45		1.726	2084.9	1.1532
5.53	1.8	2.03	536.5	1.665
7.24		2.86	2084.9	1.105
5.6	2	2.269	729.62	1.1117
7.39		4.51	1869.2	1.0016

4. COMPARISON OF PROPOSED WORK WITH PREVIOUS LITERATURES

In this section, we presented a comparison of the proposed nano circular patch antenna with other references to validate our work. Compared to all cited references in Table 4, the proposed nano circular graphene patch antenna gives better performances in term of S11, gain, and bandwidth.

5. CONCLUSION

We have designed in this work a nano circular patch antenna for terahertz band transmission systems using CST microwave software. Graphene and Rogers 4003C are used

TABLE 4: Comparison of proposed work with previous literatures

Source	Frequency (THz)	Gain (dB)	S11 (dB)	Bandwidth (GHz)
Jemima Nissiyah and Madhan (2021)	2.58 4.41	2.58 1.22	−33.7 −10.56	Not mentioned
Badr and Moradi (2020)	2.14 5.41	4.71 6.61	−24.65 −25.86	658
Shalini and Ganesh Madhan (2021)	2.05	5.02	−22	500
Samanta et al. (2021)	2.9	6.48	−28.39	120
Gupta et al. (2021)	4.104	3.8	−40	4.0629−4.1299
Dash and Patnaik (2021)	3.5	Not mentioned	−30	245
Varshney et al. (2020)	1	4.31	−18	100
Proposed antenna	3.26 4.69 5.64 6.95	3.437 5.008 5.233 6.62	−30.706 −55.54 −37.434 −26.812	653.46 4434.9

as material of patch and substrate respectively. DGS is used to increase the bandwidth of the antenna. Simulation results are very satisfactory, the S11 reaches the value of −30.706, −55.54, −37.43, and −26.812 dB, the bandwidth obtained is 653.46 GHz and 4 THz at all the frequencies cited, respectively. The gain achieved is more than 5 dB. The simulation results are very satisfactory, and the proposed antenna can be used for several applications such as WBAN applications, satellites communications, and optical transmission.

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Design of Optical Gold Printed Antenna in Terahertz Band for ON Body WBAN Applications

Bouchra Moulfi, Souheyla Ferouani, Ziani Kerarti Djalal

Abstract – **This paper presents a design and analysis of a gold nano patch circular antenna in Terahertz band for ON body WBAN applications using CST software. This antenna is simulated with Silicon substrate ($\varepsilon_r = 11.9$) and have dimensions of 63.72*83.46 μm^2 for width and length respectively, the radius of patch is taken 16μm. To analyze and compare the effect of material substrates on the proposed nano patch antenna, another types of substrates as Alumina ($\varepsilon_r = 9.9$), Rogers R04003C ($\varepsilon_r = 3.5$), RT Duriod 5880 ($\varepsilon_r = 2.2$), and RT Duriod 3210 ($\varepsilon_r = 10.8$) are used. To confirm our results, we have compared the simulation results with the paper [1] and the references cited in his work; the return loss obtained is –54.96 dB, the gain is 5.40 dB with 7.574 of directivity. The simulation results are very satisfying and the proposed antenna can be used for WBAN applications.**

Keywords – **WBAN, Printed antenna, Terahertz transmission, Optical transmission, Return loss S_{11}, Radiation pattern.**

I. INTRODUCTION

To improve the life and psychology of patients who must remain under medical supervision [2], a new wireless body network radio frequency technology called WBAN has been used (Fig. 1). A small sensor or actuator is integrated in or on the human body or even on clothing. The latter can measure blood pressure, temperature, oxygen, ECG, EEG, blood sugar, energy level, nerve signals etc [3] and then send it to a base station monitored by doctors in a database [4]. There are three types of using printed antennas in WBANs: IN-Body: the antenna is inserted into the human body or implanted under the tissue, ON-Body: the antenna is placed on the body and communicates with another wearable antenna, OFF-Body: the antenna communicates with a medical base station or another device [5]. The WBAN antenna can also be used for sports applications when an athlete is training alone or away from his coach like swimming [6], also it can be used for the evaluation of the mental and physical brain activity of racing drivers [7], etc. The WBAN antenna is a low power consumption antenna [8] and fulfills three requirements: a low radiation in the rear direction so that it does not affect the internal organs of the body, a compact size and a low height for easy integration and finally a combined effect between antenna and body.

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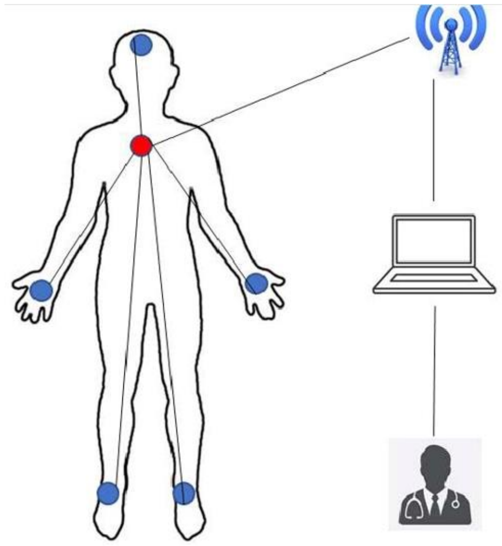

Fig. 1. WBAN applications on humman body

With these requirements, the design of a WBAN antenna will be too complicated and to solve this problem, researchers have thought of designing patch antennas with reflectors for an Omni directional radiation pattern [9]. The terahertz band above the microwave frequencies which is from [0.1ï 10] THz is the most used in the recent years, several researches have been done in this frequency spectrum like: Lens based antennas [10-11], antenna based on new materials [12-15] and yagi-Uda and dipole optical antennas [16]. The purpose of choosing this spectrum is the increase of the transmission rate, the widening of the bandwidth and also the minimization of the transmission time (real time communication).

In this work, we designed a Nano circular patch antenna for Terahertz transmission from [0.1ï 10] THz, especially for ON Body WBAN applications using Gold as material of patch with 3.205 μm of thickness and silicon substrate with permittivity ὐ$_r$ = 11.9 and 5.4 μm of thikness. This work has been compared with [1] in which he used RT Duriod ὐ$_r$ = 10.8 and Silicon ὐ$_r$ = 11.9 as substrates with 10μm of thikness. Its simulation results are presented with ANSYS HFSS software. The proposed antenna gives better results with Silicon substrate, the results are given by using CST microwave. The return loss obtained is –54.96 dB with 305.91 GHz of bandwidth and 5.40 dB of gain which is very suitable for medical application in optical transmission.

Other types of substrates have been used by keeping the same shape of the proposed antenna to evaluate the performance of the Nano-antenna in optical transmission.

II. Circular Patch Antenna Design

We designed a circular nano patch antenna that operates in Terahertz transmission and designated for ON body WBAN applications. It is consisting of a gold patch with 3.205 of thickness and a Silicon substrate ($\varepsilon_r = 11.9$, $h = 5.4$ μm). The antenna is fed by a microstrip line of impedance 50 Ω as shown in Fig. 2. The parameters of the antenna are calculated with the following equations [17]:

$$F = \frac{8.791 \cdot 10^{9}}{f_r \cdot 10^{12} \cdot \varepsilon_r^{0.5}} \cdot 10^{4}, \quad (1)$$

$$a = \frac{F}{\left(1 + \left(\frac{2 \cdot h \cdot 10^{-4}}{\pi \cdot \varepsilon_r \cdot F}\right) \cdot \ln\left(\left(\frac{\pi \cdot F}{2 \cdot h \cdot 10^{-4}}\right) + 1.7726\right)\right)^{0.5}}, \quad (2)$$

$$ae = a \cdot \left(1 + \left(2 \cdot \frac{h}{\pi \cdot a \cdot \varepsilon_r}\right) \cdot \ln\left(\frac{\pi \cdot a}{2 \cdot h}\right) + 1.7726\right)^{0.5}, \quad (3)$$

$$L_g = ll + 2 \cdot ae + 6 \cdot h, \quad (4)$$

$$W_g = 2 \cdot ae + 6 \cdot h, \quad (5)$$

where h represents height of the antenna, a radius of the antenna and ε_r the dielectric constant of the substrate used. L_g and W_g are the length and width of the substrate.

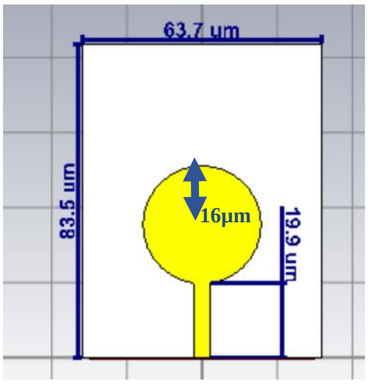

Fig. 2. Proposed nano circular patch antenna

III. Simulations and Results

A. Simulation Result with Silicon Substrate

Fig. 3 shows the simulation results of the proposed antenna with Silicon substrate ($\varepsilon_r = 11.9$).

As we can see in Fig. 6, the radiation from the back lobes is very low, so we can say that the proposed antenna is very suitable to use in Terahertz transmission especially on human body for WBAN applications.

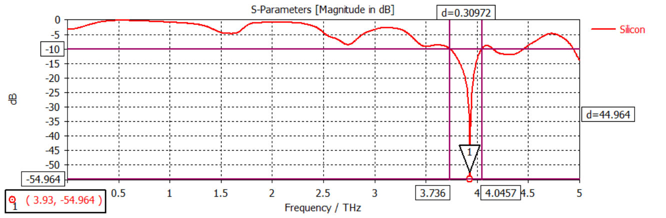

Fig. 3. Reflection coefficient parameter S_{11} of the proposed antenna with Silicon substrate

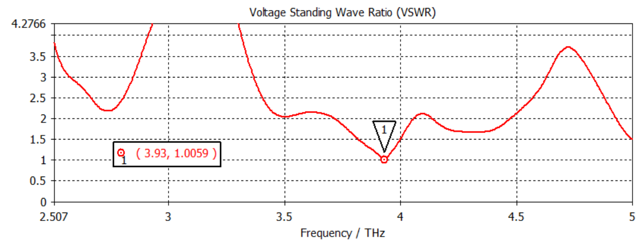

Fig. 4. VSWR of the proposed antenna

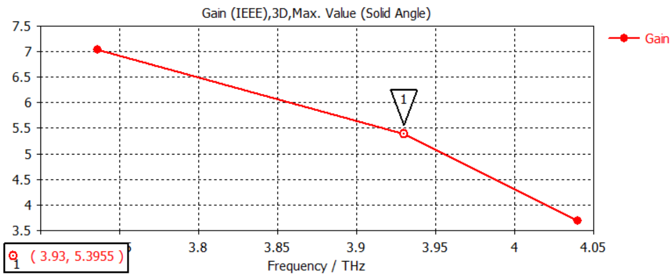

Fig. 5. Gain of proposed antenna with Silicon substrate

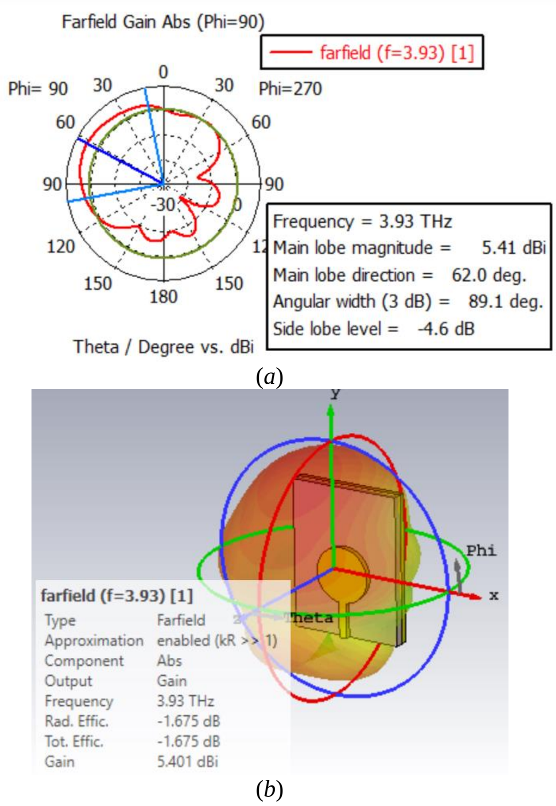

Fig. 6. Radiation pattern of the proposed antenna: (a) polar radiation pattern, and (b) 3D radiation pattern

B. *Simulation Result with others Substrates*

Others type of substrates are used, by keeping the same shape of the proposed gold patch antenna, such as Alumina (ϵ_r = 9.9), Rogers R04003C (ϵ_r = 3.5), RT Duriod 5880 (ϵ_r = 2.2), and RT Duriod 3210 (ϵ_r = 10.8) for analyzing the antenna effects. Fig. 7 shows the antenna design for each one of them and Figs. 8-12 present the simulation results obtained.

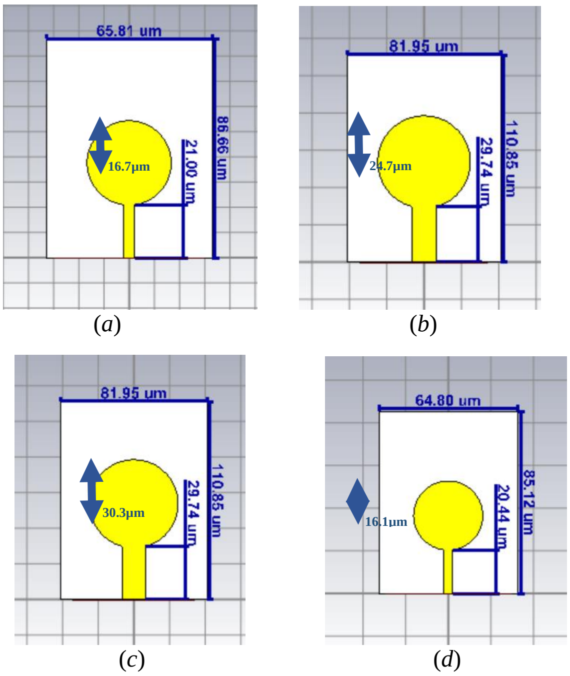

Fig. 7. Nano circular patch antenna design for each substrate: (a) Alumina, (b) RogersRO4003C, (c) RT Duriod 5850, and (d) RT Duriod 3210

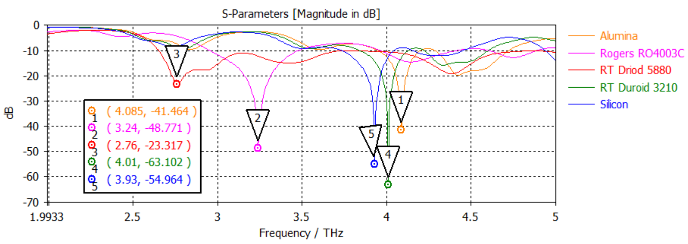

Fig. 8. Reflection coefficient parameter S11 for each substrate substrates

As we can have seen in Fig. 8, several frequencies are obtained by changing the material substrate such as 4.085 THz, 3.24 THz, 2.76 THz, 4.01 THz and 3.93 THz with the use of Alumina, Rogers 4003C, RT Duriod 5880, RT Duriod 5880 and Silicon respectively. The return loss obtained for each one of them is: –41.464 dB, –48.771 dB, –23.317 dB, –63.102 dB and –54.964 dB respectively.

As shown in Fig. 9, the VSWR in all frequencies obtained with different substrates is less than 2.

As shown in Fig. 10, the gain obtained for 4.085 THz, 3.24 THz, 2.76 THz, 4.01 THz and 3.93 THz frequencies is 5.25 dB with alumina, 4.36 dB with Rogers 4003C, 4.49 dB with RT Duroid 5880, 5.038 dB with RT Duroid 3210 and 5.3955 dB with Silicon respectively.

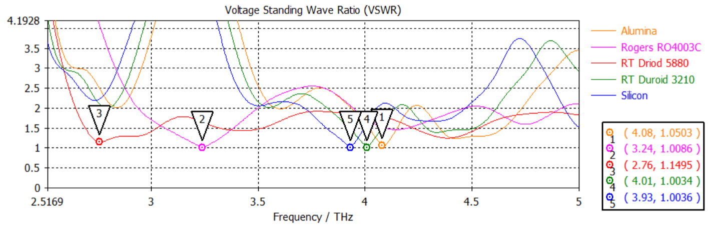

Fig. 9. VSWR of the proposed antenna

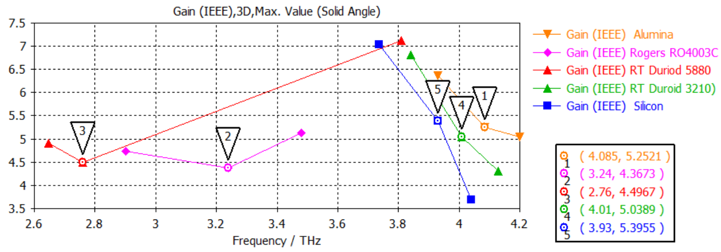

Fig. 10. Gain obtained for all the substrates

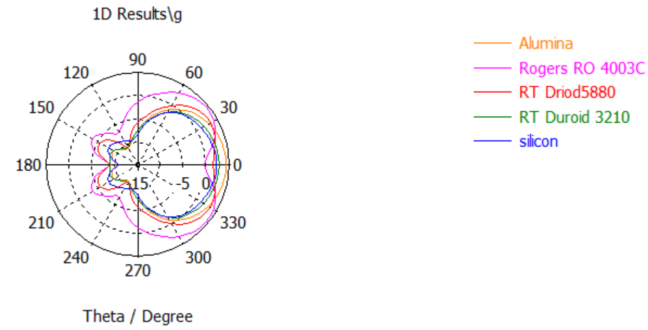

Fig. 11. Polar radiation pattern of the antenna for each substrate

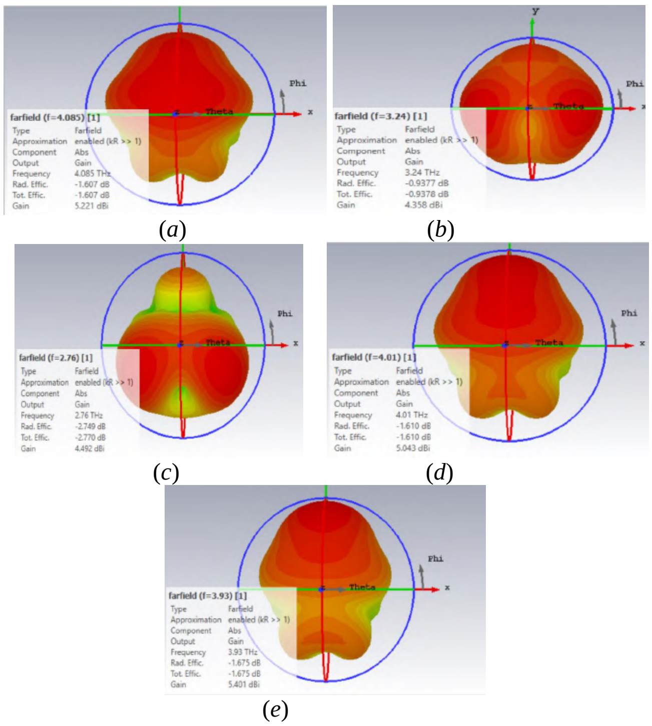

Fig. 12. 3D radiation pattern of the antenna: (a) Alumina substrate, (b) Roger 3004C substrate, (c) Roger 5880 substrate, (d) RT Duriod 3210 substrate, and (e) Silicon substrate

TABLE 1
COMPARISON OF RESULTS WITH OTHER REFERENCE

Antenna parameters	Proposed antenna		[1]	
Substrates	Silicon (ε_r=11.9)	RT Duroid 3210 (ε_r=10.8)	RT Duroid 6010 (ε_r=10.2)	Silicon (ε_r=11.9)
a [µm]	15.66	16.198	40	/
f_r [THz]	3.93	4.01	2.270	3.254
S_{11} [dB]	-54.96	-63.10	-22.39	-42.67
Gain [dB]	5.40	5.06	4.8	5.3
Directivity	7.574	6.637	3	3.1
B_p [GHz]	305.91	280.59	/	/

TABLE 2
COMPARISON OF RESULTS WITH OTHER SUBSTRATES

Antenna parameters	Proposed antenna				
Substrates	Silicon (ε_r=11.9)	RT Duroid 3210 (ε_r=10.8)	Roger 4003C (ε_r=3.55)	Alumina (ε_r=9.9)	Roger 5880 (ε_r=2.2)
a [µm]	15.66	16.198	24.77	16.7	30.36
f_r [THz]	3.93	4.01	3.24	4.085	2.76
S_{11} [dB]	−54.96	−63.10	−48.77	−41.32	−23.317
Gain [dB]	5.40	5.06	4.346	5.25	4.504
Directivity	7.574	6.637	5.294	6.719	7.229
B_p [GHz]	305.91	280.59	559.07	280.59	1166.7

As we can see in Figs. 11 and 12, the radiation from the back lobes is very low with the chosen substrates.

As it can be seen in Table 1, the proposed nano patch antenna gives better performance than [1]. The size of the proposed antenna is less than [1] with a return loss of −54.96 dB and gain of 5.40 for Silicon substrate and −63.10 dB and gain of 5.06 with RT duriod wich is very satisfying for optical transmission.

Table 2 resumes all results obtained with each substrate, we obtained several frequencies in terahertz band from [0.1–10] THz by changing the material substrate. The results obtained are very satisfying in terms of reflexion coefficient, gain and bandwidth.

IV. CONCLUSION

In this work, a nano circular patch antenna operating at terahertz frequency from [0.1ï 10] THz is designed for WBAN applications. The use of Silicon substrate material (ε_r = 11.9, h = 5.4 µm) and gold patch antenna with 3.2 µm of thickness is very suitable for on body medical application. The size of antenna is very compact, the back lobe radiation is minimum which is very satisfactory, it doesnȏt affect the human body. The proposed antenna is very suitable for use on the human body.

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NANORECTANGULAR PRINTED GOLD ANTENNA FOR ON–HUMAN BODY WIRELESS BODY NETWORK APPLICATIONS

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In this work we designed a rectangular patch antenna in the terahertz band for wireless body network (WBAN) applications using CST software. This antenna is simulated with RO4003C substrate (εr = 3.55) and has dimensions of 199 × 154 μm² for width and length, respectively. We obtained return loss of –41.408 dB, –43.918 dB, and –29.92 dB; gain of 5.32 dB, 6.21 dB, and 4.851 Db; directivity of 6.659 dB, 7.502 dB, and 6.566 dB; in 0.74 THZ, 1.148 THZ, and 1.734 THZ frequencies, respectively. The simulation results are very satisfactory, and this antenna can be used for WBAN applications.

KEY WORDS: *WBAN, printed antenna, terahertz transmission, optical transmission, return loss S11, radiation pattern*

1. INTRODUCTION

In recent years, with the emergence of several contagious diseases such as COVID-19 and its family, monitoring patients in the hospital has become very dangerous, especially to people who have chronic diseases. For this reason, the wireless body network (WBAN), which can monitor blood pressure, ECG, EEG, blood sugar, temperature, and so on (Rajawat and Gupta, 2020), has generated great interest in the medical field. A WBAN and a set of wireless sensors or actuators basically consists of a light antenna with low power consumption, small size, and a real-time response. There are three types of WBAN: in-body, where the antenna is implanted on the human body; on-body, where the antenna can communicate with another antenna located on the surface of human body; and off-body, where the antenna can communicate with another device such as cell phone or medical station monitored by doctors. This communication requires high gain, excellent efficiency, and low synthetic aperture radar absorption rate compared to the other types of WBAN (Tong et al., 2018; Le, 2021). It is difficult to design an antenna in microwave radio frequency communication with excellent performance that meets the needs of WBAN (Jeong et al., 2015).

The terahertz spectrum [0.1–10] THZ (Bhushan, 2012), which lies between infrared and microwave, has been of interest to researchers due to its excellent performance, small size, and low energy consumption. Several studies have been carried out in this frequency band, such as terahertz patch antennas based on graphene for satellite communication and special applications (Bouchra et al., 2021; Khan et al., 2020; Varshney, 2021; Moulfi et al., 2022), terahertz patch antennas for the medical field (Rubani et al., 2019; Khajawal et al., 2021; Das and Rawat, 2021), and Yagi-Uda nanoantennas and optical antennas for different types of communication (da Costa et al., 2019). Among these applications WBAN communication is the most needed in this spectrum because it requires antennas with the most miniaturization possible to facilitate the integration to human bodies. These millimeter antennas provide better performance with low power consumption (Bouchra et al., 2022).

In this work we designed a rectangular WBAN antenna with the slot technique using CST software that operates in three frequencies, 0.74 THZ, 1.148 THZ, and 1.734 THZ, using Rogers RO4003C substrate (r = 3.55) and gold as patch material and ground plane. The simulation result is very satisfactory in terms of gain, which exceeds 4.8 dB, and reflection coefficient, which exceeds –30 dB in all frequencies. This results are compared with several references cited in Table 1 to guarantee that our terahertz antenna has excellent performance with a very small size.

2. THE PROPOSED ANTENNA

In this work we designed a rectangular patch antenna fed by a microstrip line of impedance 50 Ω using CST software. We used slots on the patch and the ground plane as shown in Fig. 1. The material chosen for the upper radiating element (the patch) and the lower element (the ground plane) is gold with a thickness of 8 μm. RO4003C (εr = 3.55) with thickness h = 15 μm is the dielectric material substrate used for our proposed antenna. The dimensions of the proposed antenna are related to the frequency of the chosen application and calculated with the following equations (Werfelli et al., 2016):

$$w=\frac{3*10^{8}}{2*fr*10^{12}*\left(\frac{eps+1}{2}\right)^{0.5}} \tag{1}$$

$$L=\left(\frac{3*10^{8}}{2*fr*10^{12}*(epseff)^{0.5}}\right)*10^{6}-(2*\Delta l) \tag{2}$$

TABLE 1: Comparison of proposed work with previous literature

	Frequency (GHZ)	S11 (dB)	Gain (dBi)	Directivity
Proposed antenna	740 1148 1734	–41.408 –43.918 –29.92	5.32 6.21 4.851	6.659 7.502 6.566
Rubani et al. (2019)	852	–20	2.5	2.6
Mirhadi (2021)	5.8	–29	0.5–3.9	NA
Rashid et al. (2022)	3.1 6.85 10.6	NA	−3.164 2.780 4.989	NA
Sayem et al. (2022)	2.4	–26	2.5	NA
Utsav and Badhai (2021)	2.4 5	–22 –27	3.7	NA
Afruz (2021)	2.45	–20.18	1.85	2.3
Bouchra et al. (2022)	3930 4010	–54.96 –63.10	4.40 5.06	7.574 6.637
Rubani et al. (2019)	2270 3254	–22.39 –42.67	4.8 5.3	3 3.1

NA, not available

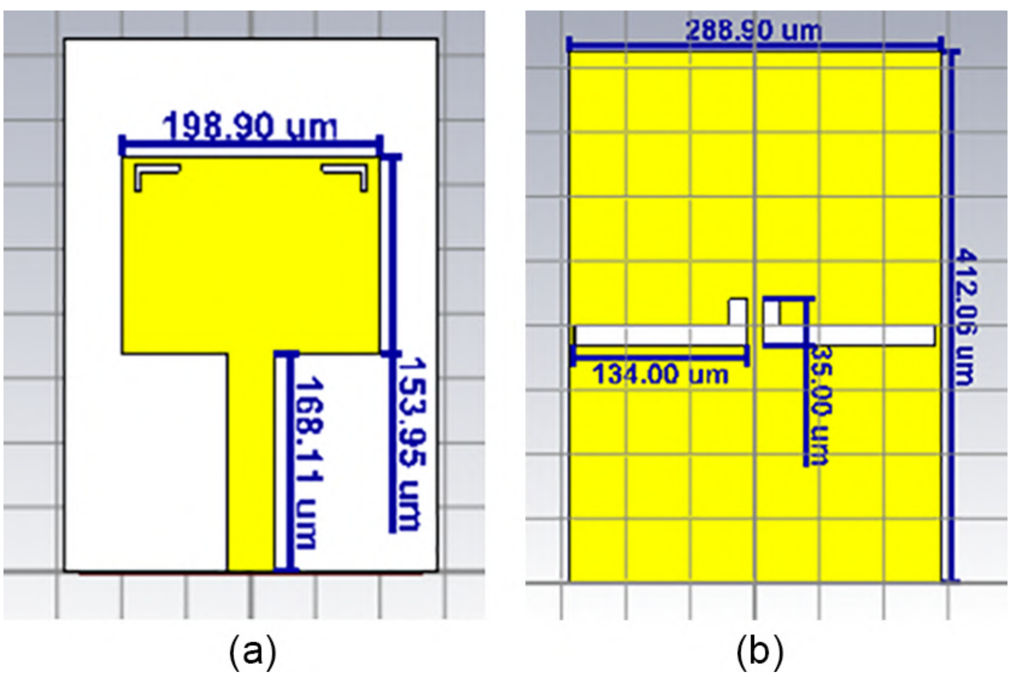

FIG. 1: (a) Front view of the rectangular proposed patch antenna; (b) rear view of the rectangular proposed patch antenna

$$Wg = w + 6 * h \tag{3}$$

$$Lg = ll + l + 6 * h \tag{4}$$

3. SIMULATION AND RESULT

The simulation result of the proposed antenna gives three frequencies 0.74 THZ, 1.148 THZ, and 1.734 THZ, which have excellent reflection coefficients of –41.408 dB, –43.918 dB, and –29.92 dB, respectively, as shown in Fig. 2. The bandwidth obtained are 27.4 GHZ, 108.9 GHZ, and 89.76 GHZ in frequencies obtained, respectively.

As shown in Fig. 3, the voltage standing wave ratio (VSWR) in all frequencies obtained with RO4003C substrate (εr = 3. 55) is less than 2, and Fig. 4 represented the gain in all this frequency.

As shown in Figs. 5 and 6, the proposed antenna has an excellent gain of 5.32 dB, 6.21 dB, and 4.851 dB in the frequencies 0.74 THZ, 1.148 THZ, and 1.734 THZ, respectively.

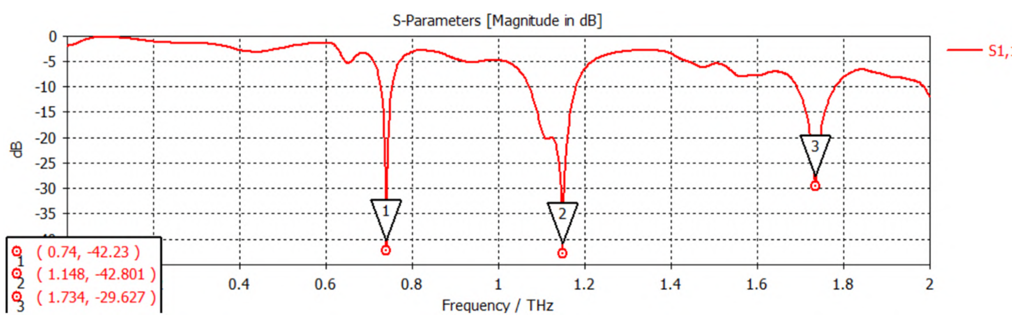

FIG. 2: Reflection coefficient S11 of proposed antenna

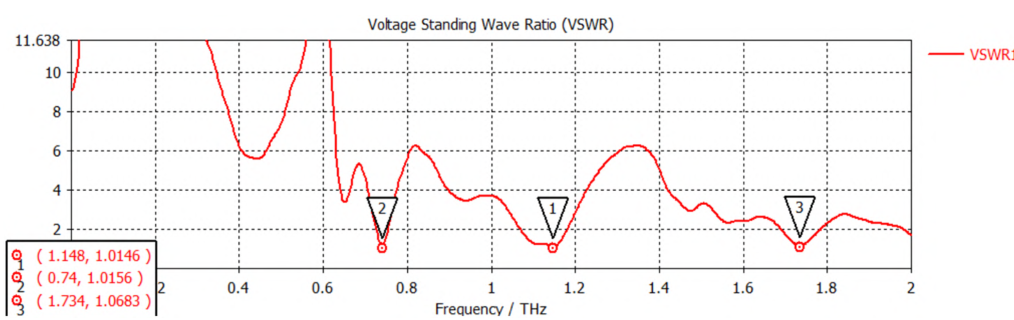

FIG. 3: VSWR

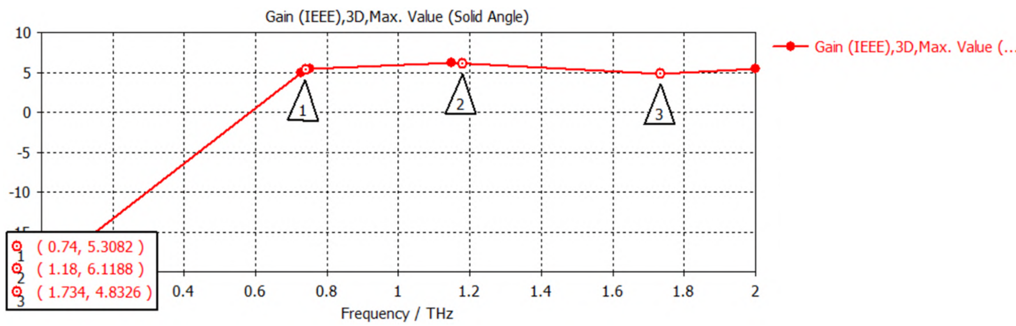

FIG. 4: Gain

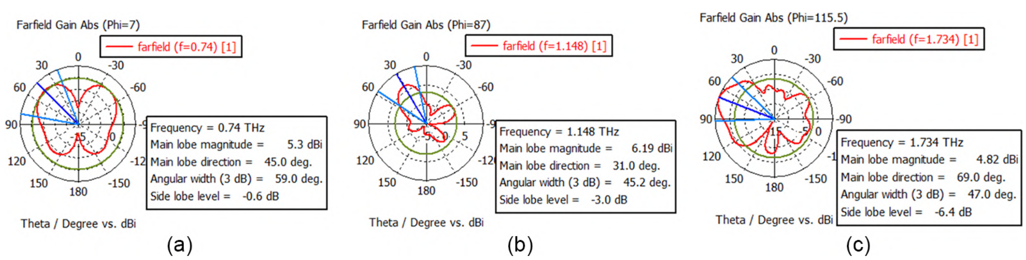

FIG. 5: Polar radiation pattern: (a) in frequency 0.74 THZ; (b) in frequency 1.148 THZ; and (c) in frequency 1.734 THZ

As we can see in Figs. 5 and 6, the radiation pattern from the back lobes is low compared to the front lobe, where it is safe to insert on-body WBAN. The proposed antenna is suitable to use on the human body for WBAN applications.

Figure 7 represents the current density of our proposed antenna at all deferent frequencies 0.74 THZ, 1.148 THZ, and 1.734 THZ.

4. COMPARISON OF PROPOSED WORK WITH PREVIOUS LITERATURE

Table 1 summarizes our proposed antenna results compared with other current works. We noticed that our antenna gives a very good result in term of gain, s11, and directivity.

5. CONCLUSION

In this work, a nanorectangular patch antenna with slots on the patch and ground plane has been designed for on-body WBAN applications. Three frequencies are obtained at 0.74 THZ, 1.148 THZ, and 1.734 THZ, respectively, with a very good return loss of –41.408, –43.918, and –29.92. The use of gold for the patch and Rogers RO4003C for the substrate gives an excellent result in terms of reflection coefficient, bandwidth, gain, and directivity. The size of the proposed antenna ($199 \times 154\ \mu m^2$) is very small and

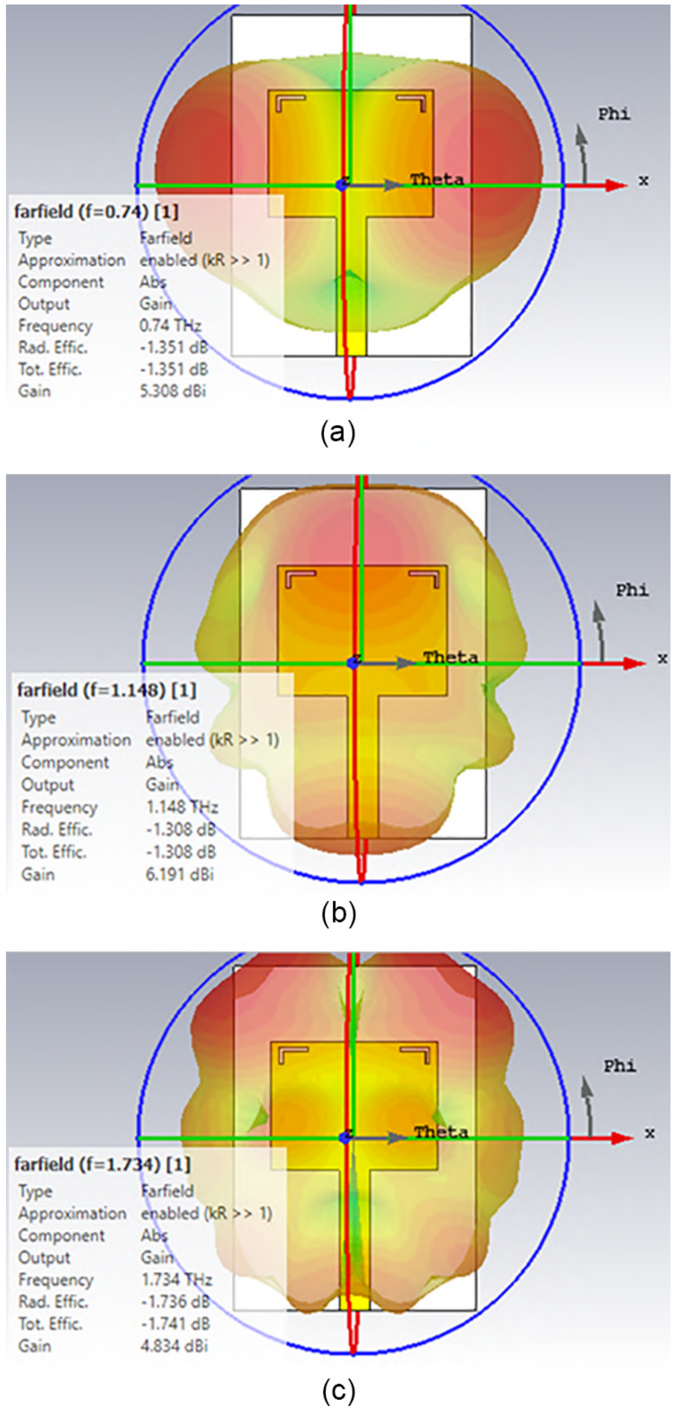

FIG. 6: 3D radiation pattern: (a) in frequency 0.74 THZ; (b) in frequency 1.148 THZ; and (c) in frequency 1.734 THZ

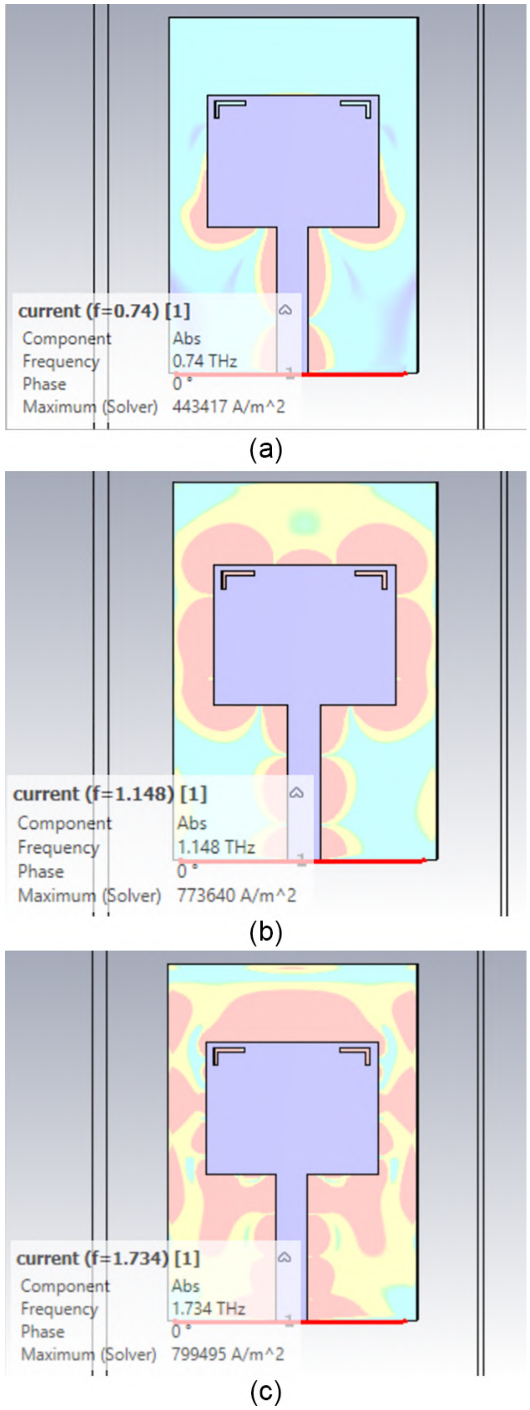

FIG. 7: Current density: (a) in frequency 0.74 THZ; (b) in frequency 1.148 THZ; and (c) in frequency 1.734 THZ

compact, which is easy to integrate on the human body and is very suitable for WBAN applications.

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NANO GRAPHENE PATCH ANTENNA WITH SLIT FOR TERAHERTZ TRANSMISSION

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In this work, using CST simulation software, we simulated a nano rectangular graphene patch antenna for optical transmission. The chosen dielectric substrate is RT6010 (εr = 3.55) with thickness 2.2 μm. The proposed antenna gives one peak of frequency at 6 THz with return loss of –43.531 dB and a radiation pattern of 5.26 dBi. To improve the performance of the antenna, we simulate the antenna with a relaxation time of 1 ps, 3 ps, and 5 ps. The proposed antenna can be integrated and used for optical transmission.

KEY WORDS: *graphene antenna, patch antenna, S11, radiation pattern, substrate, terahertz transmission, optical transmission*

1. INTRODUCTION

Graphene is one of the most promising materials in the development of new technologies because of its two-dimensionality (Tewari, 2002). Graphene is extracted from graphite (Tewari, 2002; de Sousa et al., 2023). It is a layer of single carbon atoms arranged in a hexagonal pattern that resembles a honeycomb (Fuchs et al., 2011). This material has proven to be an excellent conductor of heat and electricity (Dash and Patnaik, 2021). It is also characterized by a low active resistance at room temperature (Benlakehal et al., 2023). The electrons of graphene present greater mobility than other materials (Kumar and Yaduvanshi, 2023). Their speed, reaching 1/300 the speed of light, opens interesting possibilities for use in diagnosis. Tt is also transparent, as it absorbs 2.3% of white light, and its extremely fine structure is up to 100 times stronger than steel with up to 20% extensibility in length or width. A water-permeable oxidized graphene membrane is completely impermeable to gases, so it can be used for filtration (Shalini, 2021).

This type of material is commonly used in the optical band (0.1–10) THZ, which is located between the microwave and the infrared. It is characterized by a strong penetrating power and a high data rate in the field of telecommunication. This far of an infrared spectrum can be used in the biomedical field as telemedicine (Bouchra et al., 2022; Afruz, 2021; Rubani et al., 2019), or in the special transmission (Moulfi et al., 2022; Bouchra et al., 2022; Llatser et al., 2012).

In this work, using CST simulation software, we design a rectangular patch antenna with this new graphene material with the following characteristics: chemical potential 2 ev, thickness 60 µm. The chosen dielectric substrate is RT6010 (εr = 3.55) with thickness 2.2 µm. Then, we make a change of relaxation time of the patch material and of the ground planes to evolve the performance of the antenna.

2. ANTENNA DESIGN

In this article, using CST simulation software, we design a rectangular patch antenna fed by a 50 ohmmicrostripline. The upper radiating part is called “patch” and the lower part is called the “ground plane,” and it is based on a new material: graphene. The dielectric substrate between them is RT6010 (εr = 3.55), and the dimensions used to calculate our simulated antenna is (Werfelli et al., 2016):

$$w = \frac{3*10^8}{2*fr*10^{12}*\left(\frac{eps+1}{2}\right)^{0.5}}, \quad (1)$$

$$L = \left(\frac{3*10^8}{2*fr*10^{12}*(epseff)^{0.5}}\right)*10^6 - (2*\Delta l), \quad (2)$$

$$Wg = w + 6*h, \quad (3)$$

$$Lg = ll + l + 6*h. \quad (4)$$

3. SIMULATION AND RESULTS

Figure 1 shows the dimension of the rectangular proposed graphene patch antenna, and Fig. 2 shows the reflection coefficient S11 of the proposed antenna. The simulation re-

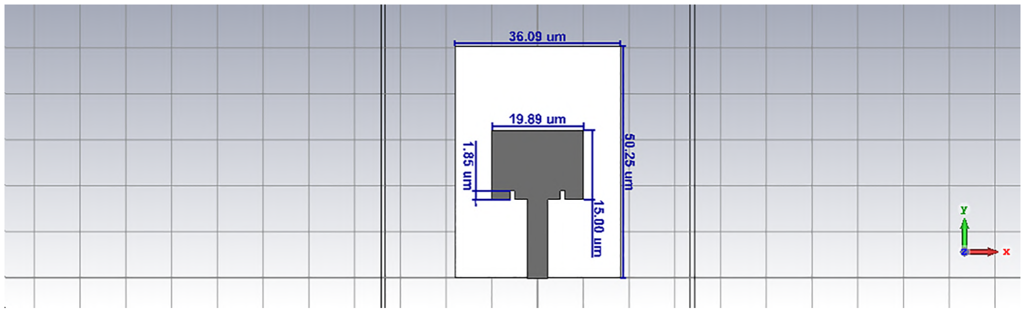

FIG. 1: The rectangular proposed graphene patch antenna

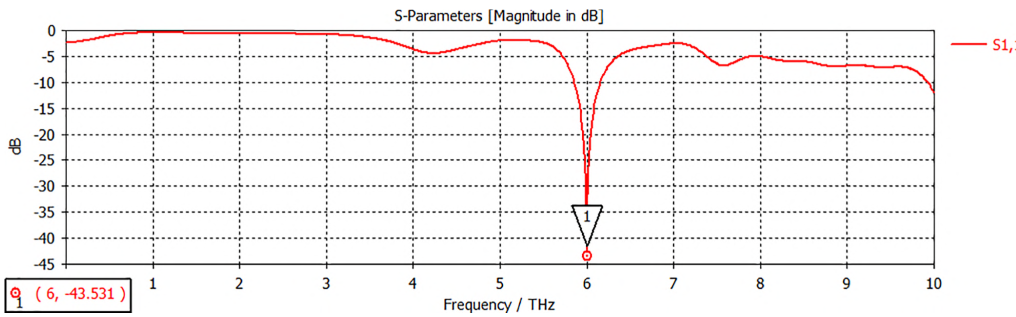

FIG. 2: Reflection coefficient S11 of proposed antenna

sult of the proposed antenna gives one picture of frequency at 6 THz with return loss of –43.531 dB and a radiation pattern of 5.26 dBi.

4. RELAX TIME VARIATION

To improve the characteristics of our proposed antenna, we make a study on one of the material parameters of patch and ground plane graphene. We simulated the antenna with a relaxation time of 1 ps, 3 ps, and 5 ps. The results of the simulation are presented in Fig. 3. Figures 4–7 represent the different results of our proposed antenna with the temperature change of the relationship between the patch material and the ground plane. The simulation result of this antenna gives the reflection coefficient of –43.531, –26.766, and –27.336, a VSWR of 1.0134, 1.0962, and 1.0898, and a gain of 5.22 dBi, 5.62 dBi, and 6 dBi at frequencies of 6 THz, 5.97 THz, and 6.19 THz with relaxation time of 1 ps, 3 ps and 5 ps.

5. COMPARISON OF PROPOSED WORK WITH PREVIOUS LITERATURES

Table 1 summarizes our simulation results and makes a comparison with various current works.

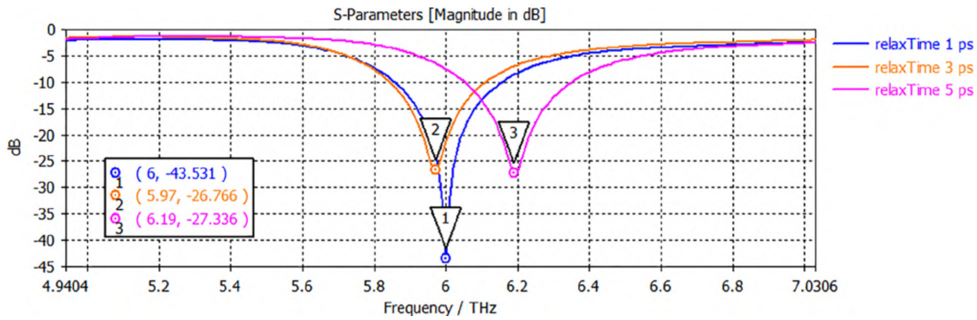

FIG. 3: Reflection coefficient S11 of proposed antenna with different relax time 1 ps, 3 ps, and 5ps

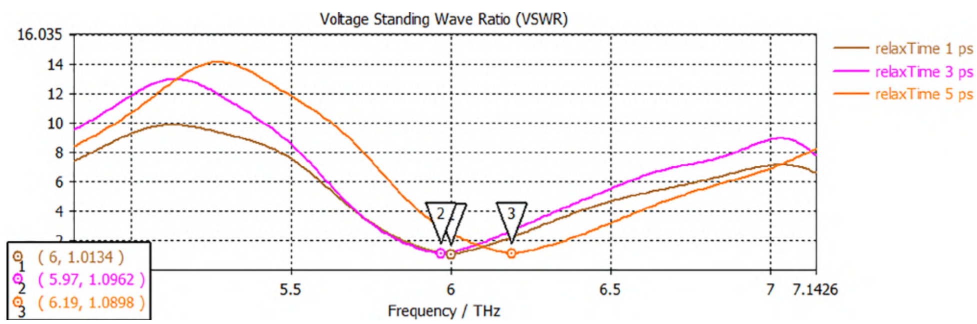

FIG. 4: VSWR of proposed antenna with different relax time 1 ps, 3 ps, and 5 ps

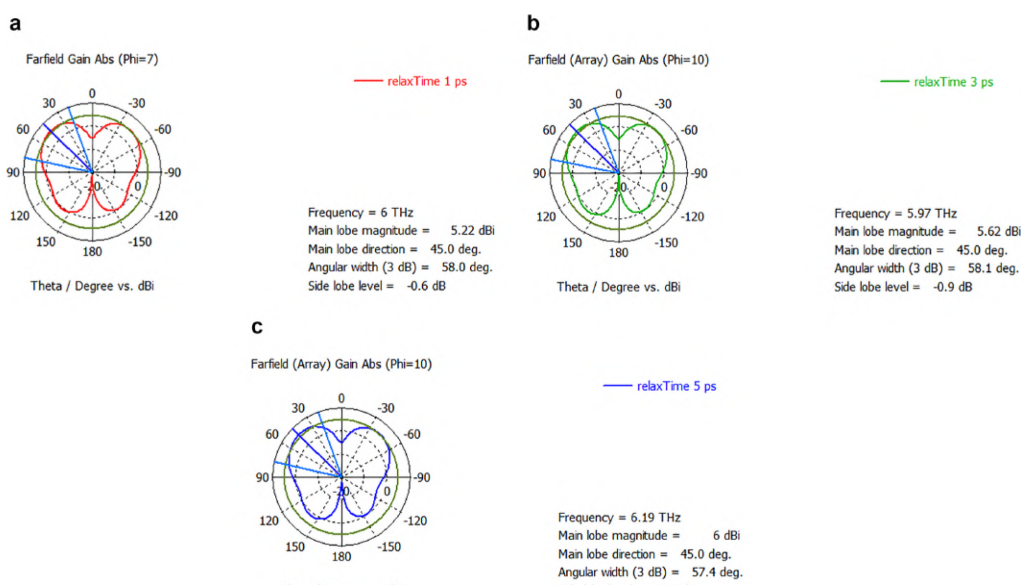

FIG. 5: Polar radiation pattern of proposed antenna with different relax time (a) 1 ps; (b) 3 ps; and (c) 5 ps

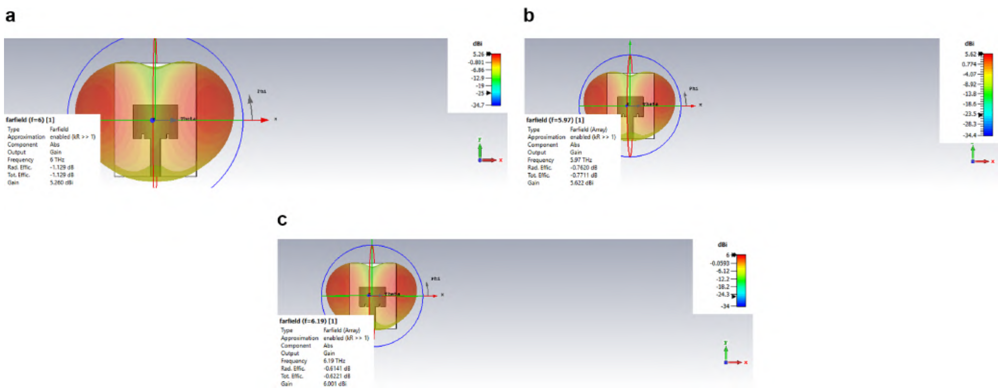

FIG. 6: 3D radiation pattern of proposed antenna with different relax time (a) 1 ps; (b) 3 ps; and (c) 5 ps

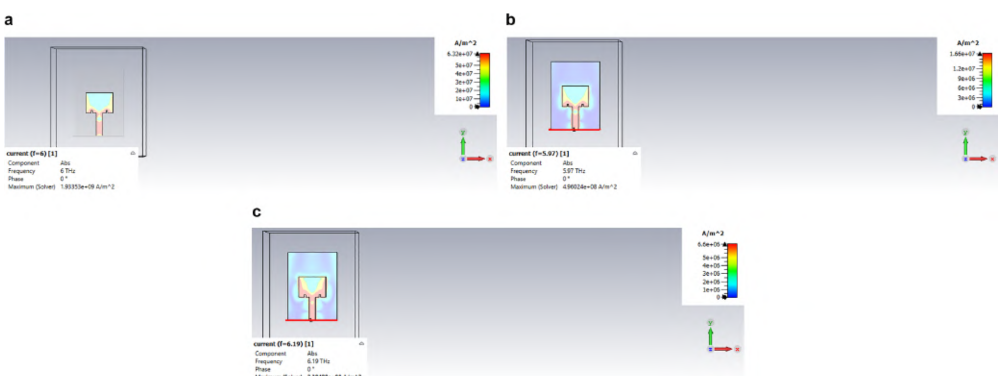

FIG. 7: Current density of proposed antenna with different relax time (a) 1 ps; (b) 3 ps; and (c) 5 ps

TABLE 1: Comparison with various current works

	Relax time (ps)	**Frequency (THz)**	**S11 (dB)**	**Gain (dBi)**
Proposed antenna	1	6	–43.531	5.26
	3	5.97	–26.766	5.62
	5	6.19	–27.336	6
Tewari (2002)		5.66	–48.25	4.50
Abohmra et al. (2019)	0.8	4.546	–41.258	2.93
	0.5	5.347	–41.23	1.41
Rubani et al. (2019)		2.270 3.257	–22 –42	4.8 5.3
Rubani et al. (2019)		0.852	–19	2.5

6. CONCLUSION

The optical band is a range of frequencies in the electromagnetic spectrum that corresponds to the region of wavelengths where visible light is emitted and detected by the human eye. However, the optical band can also include higher frequencies and shorter wavelengths that are not visible.

In this work, a nano graphene rectangular patch antenna using slit technique is designed using CST software for emitting or receiving electromagnetic waves at frequencies in the terahertz (THz) range. This allows them to penetrate many materials while providing high spatial resolution. The size of this antenna is very small (19.89*15 μm^2), which facilitates its integration in different devices and a real time response. The antenna gives excellent results using a new patch material, graphene. We obtained a reflection coefficient of –43.531, –26.766, and –27.336, a VSWR of 1.0134, 1.0962, and 1.0898, and a high gain of 5.22 dBi, 5.62 dBi and 6 dBi at frequencies of 6 THz, 5.97 THz, and 6.19 THz with relaxation time of 1 ps, 3 ps and 5 ps. This terahertz antenna has excellent characteristics and can be used in a variety of applications (Semenov et al., 2008; Armand, 2011; Samanta et al., 2021).

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