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Graphene Patch Antennas 'RGPA' & 'EGPA' - A Novel Comparative Study

[1]Gaurav Tewari, [2]Rajveer Singh Yaduvanshi

Abstract— The novel Graphene Patch Antenna 'GPA' at Terahertz frequency operation requires effcient nano- materials to operate within the millimeter wave and THz spectrum. In this paper, doped graphene is used to improve the performance of two types of patch antennas, a rectangular and an elliptical antenna. The surface conductivity of conventional (non-doped) graphene is first modeled prior to the design and simulation of the two graphene based antennas in an electromagnetic solver. Next, different graphene models and their corresponding surface conductivities are computed based on different bias voltages or chemical doping. These configurations are then benchmarked against a similar antenna based on conventional metallic (copper) conductor to quantify their levels of performance improvement. The graphene based antennas showed significant improvements for most parameters of antenna than that of the conventional antenna. Besides that, the higher chemical potentials resulting from higher biasing voltages also resulted in this trend. Finally, the elliptical graphene patch antenna 'EGPA' indicated better reflection performance, radiation effciency and gain than a rectangular graphene patch antenna 'RGPA' operating at the same resonant frequency. Along that it both gives best result when compared to normal conventional patch antennas.

. ***IndexTerms— HFSS, CST, GPA, CNT, FEM.***

1 Introduction

Improvement of THz radio antennas is generally late [1]. Other than considering their proficiency upgrades from the point of view of electromagnetism, understanding their physical and materials science viewpoints is additionally urgent [2]. The swarming expanding of remote interchanges range and requests for transmission capacities have brought about the abuse of millimeter-wave (mm-wave) and TeraHertz (THz) groups possibly for applications, for example, imaging, spectroscopy, detecting and identification [3]. Since most materials retain THz radiation, THz signals distinguished utilizing a reception apparatus might be utilized as a part of sub-atomic spectroscopy or fingerprint identification in detecting explosives, medications, substance and organic weapons. The constrained range because of high way misfortune and low recipient affectability requires the accessible episode influence at an indicator to be boosted utilizing an effective receiving antenna.

A few past examinations have explored THz microstrip radio antennas' substrates, while others researched its conductive components [4], for example, gold and plati-

[1]**Gaurav Tewari** is currently pursuing Ph.D in Electronics and Communication Engineering
E-mail: gauravtewari1947@gmail.com
ORCID https://orcid.org/ *0000-0001-6836-2778*

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[2]***Rajveer Singh Yaduvanshi*** *is currently Associate Professor in AIACTR (Govt. of N.C.T of Delhi)*

num. THz reception apparatuses must be proficient to guarantee high pick up, other than being wideband, scaled down in size and financially savvy. Photoconductive recieving antennas have been recommended for such applications. Notwithstanding, the regularly poor impedance coordinating between these reception apparatuses and their photomixers frequently prompts the debasement of recieving antenna effectiveness.

An other option to beat this downside is to use microstrip fix radio antennas [5]. Their normal use as leading materials in the mm-wave and THz recurrence groups is because of their high conductivity and anti-oxidization conduct in air [6]. Be that as it may, metals are regularly lower in conductivity in the THz frequencies than in DC or microwaves.

Despite what might be expected, metallic thin film might be inclined to smaller scale breaks [7]. Nanomaterials, for example, graphene and Carbon Nanotubes (CNTs) are reasonable choices to beat metallic misfortunes in these applications. For instance, the resistivity of a solitary divider (SW) CNT is lower than that of a strand gold with a similar width, making it a noteworthy rousing element in using CNTs for creating nanoantennas [9, 10]. This prompts expanded entrance of field in metals, high surface protection and thusly, debasement of the radiation efficiency in metallic THz reception apparatuses [7, 8]. In any case, its high (20 kω to 10 Mω) impedance confounds coordinating between CNT RF gadgets and other regular 50 Ω RF gadgets, for example, metal multilayers on dielectrics or metal semiconductor hetero structures. Despite the fact that 50 Ω impedance can be accomplished utilizing packaged CNTs, controlling this procedure is fairly intricate. It is additionally a promising material for creating the remote correspondence frameworks of cutting edge [12], which require high portability, low power and broadband activity [13]. Unexpectedly, graphene, other than its incredible conductivity, likewise includes controllable and tuneable 50 Ω impedance [14]. Graphene nanoribbon (GNR) can be conceivably connected in remote nano-sensors and gadgets working in the THz band [15, 16]. At the point when coordinated with flexible dielectric substrates, GNR can likewise defeat the inclination of miniaturized scale breaks in metallic thin films for conformal recieving wires. For instance, a conformal microstrip fix comprising of two parallel electric conduits isolated by a dielectric material was proposed in [17], created by thin film affidavit and nanolithography methods [18]. Other than tackling the confuse issues in the THz administration [4], this essential topology is additionally generally utilized because of its scaling down capacity and conformality [10]. In the interim, an investigation at first glance conductivity of the graphene sheet and the outline of a GNR-based fix was talked about in [19]. A graphene-based rectangular microstrip fix THz recieving wire utilizing a Silicon Dioxide (SiO_2) substrate was displayed in [14]. The proposed radio wire reverberated at 0.75 THz and highlighted 5.09 dB and 86.58% pick up and radiation effectiveness, individually. A straightforward graphene reception apparatus was additionally contemplated inside 5.66 to 6.43 THz band. Its radiation proficiency and pick up were observed to be 37.17% and 3.27 dB, individually, at 6 THz reverberation [20]. Other than that, quartz substrate was utilized to outline a tunable triangular graphene-based receiving wire for task at 2.60 THz. The subsequent pick up and radiation effciency, approved numerically, were 5.97 dB and 82.7% when one-sided with a 0.5 eV concoction potential [21]. From the writing survey, it is approved that graphene displays fantastic properties as far as info impedance coordinating, recurrence configurability, and stable radiation examples and impedance after tuning [22].

In this paper, an examination of the changes in the level of surface conductivity and impedance by means of concoction doping or potential biasing is performed. Two diverse graphene based radio wires are examined as far as radiation effectiveness, pick up, directivity and reflection coefficient. To accomplish this goal, the graphene layer's surface impedance is first displayed numerically in view of various doping (biasing). These surface properties are then connected on the two graphene-based reception apparatuses: a rectangular and a curved fix radio wire that encouraged utilizing microstrip transmission lines. It has been watched that the advancement of the circular fix created a greatest radiation proficiency and pick up of 96% and 7.21 dB, individually, by means of a 0.5 eV compound potential. They, by a wide margin, are the best qualities detailed in open writing examined numerically. The association of the paper is as per the following. Segment 2 depicts the demonstrating of the recurrence subordinate properties of the graphene-based surface conductivity. Next, the parameters are actualized on the proposed reception apparatuses in the accompanying segment. Other than the surface properties, in this segment the impacts of the geometrical parameters on the reception apparatus execution in the outline and numerical reenactment are likewise examined. The outcomes are exhibited and talked about in Section 4 before some finishing up comments.

2 Designing of 'Graphene Patch Antenna'-'GPA'

The graphene monolayer is a two-dimensional material composed of carbon atoms bonded in hexagonal structures. It can be represented by an infinite sheet with surface conductivity, which can be modelled via Kubo formula [23].

$$\sigma(\omega) = \sigma_{\text{intra}}(\omega) + \sigma_{\text{inter}}(\omega) \quad (1)$$

where j is the imaginary unit, q_e the electron charge, k the reduced Plank constant, K_B the Boltzmann's constant, T the temperature, μ_c the chemical potential, and ω the operating angular frequency. Scattering rate $\Gamma = 1/2\tau$ represents its loss mechanism and τ the relaxation time. The value of τ in previous literature ranges between 10^{-11} and 10^{-14} [5]. In this work, the utilized τ is 3 10^{-12} [23, 24]. The two terms of the surface conductivity are calculated using Eqs. (2) and (3). The first term (intraband term) dominates the value of total conductivity in the range of frequency below 5 THz, whereas the second term (interband term) has no significant effect on the total surface conductivity within this band (see Figure 1(a)). Figure 1(b) shows the effect of changing graphene chemical potential μ_c on the surface conductivity. It depends on the carrier density, which can be controlled by gate voltage, electric bias field, or chemical doping. Increasing μ_c leads to the increase in graphene surface conductivity, which shifts antenna resonances to higher frequencies. The shifting of antenna resonance, due to changing μ_c enhances flexibility for the design of tuneable antennas, especially within the THz band.

The ariation of μ_c enables the resonant frequency tunability feature. Meanwhile, the value of the chemical potential μ_c is electrically controlled by varying the bias voltage (gate voltage, $V g$) on the graphene layer. The relation between chemical potential and the bias voltage is explained by the following formula .

The model of single layer graphene material can be made by 2 Dimensional surface conductivity. We derive surface conductivity as in equation 5

$$\sigma(\omega, \mu_c, \tau, T) = -J \frac{q_e^2 K_b T}{\pi h^2 (\omega - 2jT)}$$

$$\times \{ \frac{\mu_C}{K_b T} + 2 \ln(e^{\frac{-\mu_C}{K_b T}} + 1) \} \quad (2)$$

Where ' ω' is angular frequency 'μ_C' is chemical potential 'T' is scattering rate also called transport relaxation time. 'K_b' is Boltzmann constant and 'h' is plank constant in reduced state. The intraband relation gives higher accuracy for low Thz frequencies. When considered $\mu_C = 0ev$ at room temperature of approx 300K we get following simplified equation

$$\sigma\,(intra) = J \frac{q_e^2 K_b T}{\pi h^2 (\omega)} [2 \ln(2)] \quad (3)$$

$$\sigma_{inter}(\omega) = \frac{e^2}{4h} [H \left\{ \frac{\omega}{2} \right\} + i \frac{4\omega}{\pi} \int_0^\infty \frac{H(\varepsilon) - H(\frac{\omega}{2})}{\omega^2 - 4e^2} d\varepsilon] \quad (4)$$

Where ' e' is electron charge 'μ_C' is chemical potential T' is scattering rate also called transport relaxation time. 'K_b' is Boltzmann constant and 'h' is plank constant in reduced state.

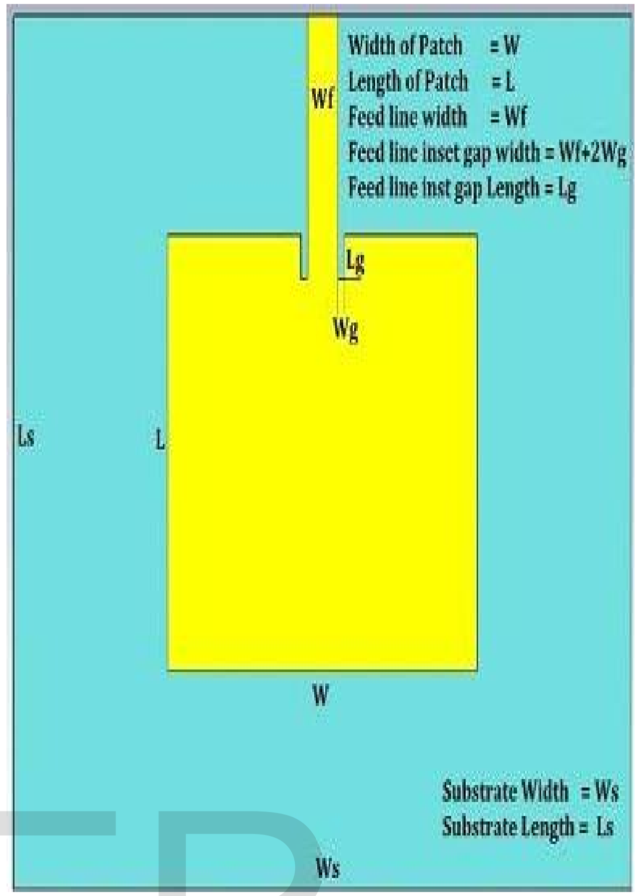

Fig- 1 Rectangular Patch Antenna Design with Microstrip line Feeding

'The above figure demonstrates the design overview of novel "Graphene Microstrip Patch Antenna"- GPA. It has rectangular patch made with graphene material having 'L' and 'W' as length and width of the patch , L_1 and W_1 as length and width of microstrip line feeding. L_s and W_s as length and width of substrate. Here 'SiO2' is used as substrate material. 'h' is the height, also called thickness of substrate used. Graphene material is also used as infinite ground plane of antenna .

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Parameters Resonant Frequency Patch width	Sym- bol fr W	Value 1.291 THz 80 μm
Patch Length Substrate length and width	**L**	W × 3/4 2 ∗ L × 2 ∗
Substrate thickness	**h**	W/20
Substrate dielectric constant	**εr**	3.5
Length of the microstrip feed line	**Lf**	(L/2+ Lg)
Width of the microstrip feed line	**Wf**	W/10
Length of the inset gap of the microstrip feed line	**Lg**	L/10
Width of the inset gap of the microstrip feed line	Wg	Wf/10

Table 1 Design Parameters Dimensions of Novel 'GPA'

Table 1 demonstrates the design parameters of 'Novel GMPA' of graphene as its patch and having rectangular architecture of length L = 10.71 µm and width W=14.87 µm along with micro-stripline feeding. Substrate used is silicon dioxide (SiO_2) having dielectric constant 'ε_r = 3.9' and having thickness 'h = 1.8 µm'. Feeding is given by simple microstrip line of dimension L_1= 8.595 µm and W_1= 2.664 µm as its length and width.

The substrate is made of silicon dioxide material having length L_S= 27.9 µm, Width W_S= 66.67 µm and height h=1.8 µm

3 Geomatrical Parameters Novel of 'Graphene Patch Antenna'- 'GPA'

The graphene-based microstrip patches antenna depicted in Figure 3 consists of a conducting patch and a feeding line on top of a thin layer of dielectric substrate (2.2 $\leq \varepsilon_r \leq$ 12) [17]. The ground plane is placed on the bottom of this layer. The conducting patch generally can be designed using different shapes [26]. Two typical microstrip patch antenna topologies are chosen for their simplicity and ease of fabrication: a rectangular-shaped and an elliptical-shaped patch antenna, and both models are used to validate the calculated surface properties in the previous section. The thickness of the thin polyimide substrate, which separates the radiating patch from the ground plane must comply with its traditional limitation of h λ and $0.003\lambda_0$ h 0.05λ. It is to prohibit the generation of surface waves in the classical metallic patch antennas [17]. To study the geometrical effect on the behaviour of both (rectangular and elliptical) antennas, the width and length of rectangular patch are made equal to the major and minor axes of the elliptical patch, respectively, in a way that both patches are designed with symmetrical dimensions (width and length of the patch, substrate, strip feedline and inset feed gap), which are kept constant for both patches so that satisfactory reflection coeffcient will be produced. The differences in shape imply that different surface areas will be produced for different patch antenna types.

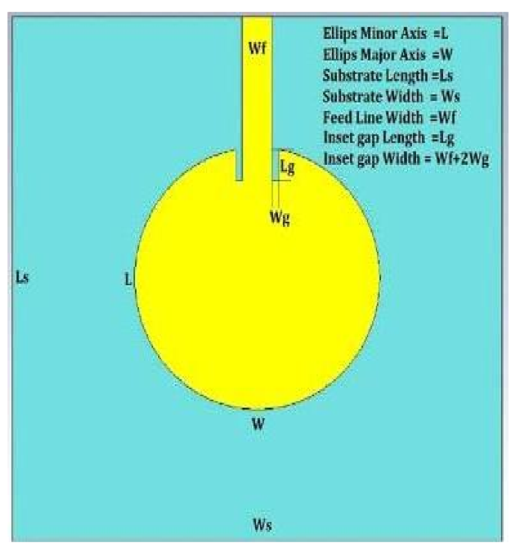

Fig- 2 Circular Patch Antenna Design with Microstrip line Feeding

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To design a rectangular patch antenna, the resonant frequency is selected as f_r = 1.290 THz, and the thickness of the polyimide substrate is h = 4 µm. The other dimensions of the rectangular patch are computed and approximated as listed in Table 1. The rectangular and elliptical patch antennas are simulated over the 0.3 THz to 3 THz frequency band using pure copper as conducting layers and polyimide as its substrate. To simplify the analysis, the dispersion of polyimide substrate is not considered in simulations. It is also the default setting for this particular material in the simulator's library.

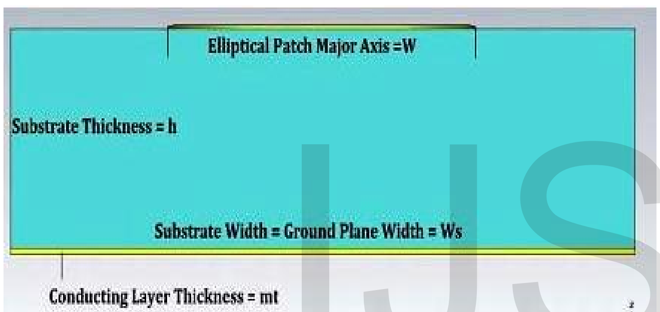

Fig- 3 Cross Section of Both Antennas

4 Results and Discussions

The pure copper based patch antenna (Patch1) resonance frequency (f_r) is 1.291 THz, which is then decreased to 1.278 THz when the pure copper conducting layers are replaced using *tt*0. Resonance is increased to 1.296 THz and 1.299 THz when the conducting materials are replaced by *tt*1 and *tt*2, respectively. This means that the resonance can be tuned by increasing or decreasing the chemical potential. The simulation results for the graphene-based antenna

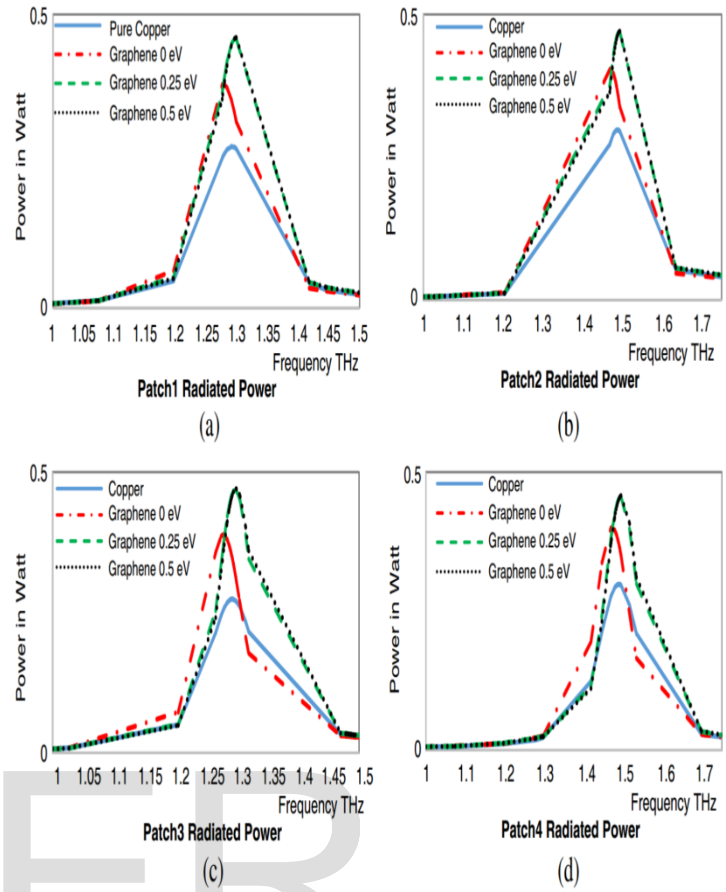

Figure 4. Radiated power for: (a) Patch1, (b) Patch2, (c) Patch3 and (d) Patch4. Legend: pure copper (solid blue line), *tt*1 (red dashed dotted line), *tt*2 (green dashed line) and *tt*3 (black dotted line).

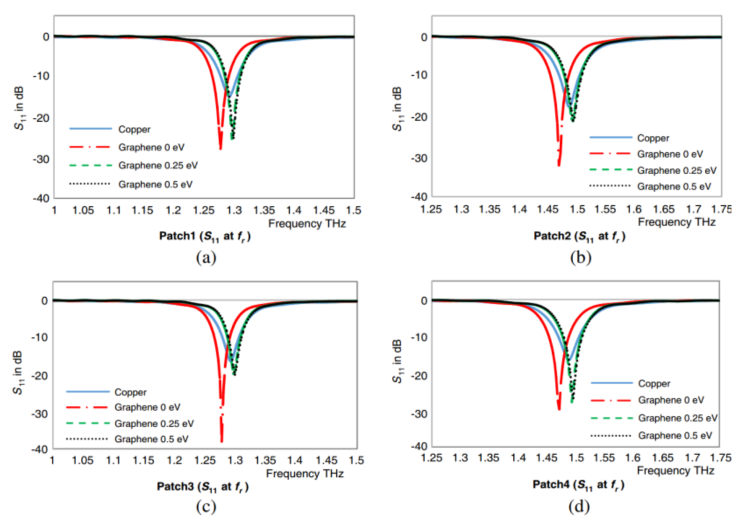

Figure 5. Reflection coefficients for: (a) Patch1, (b) Patch2, (c) Patch3, (d) Patch4. Legend: pure copper (solid blue line), *tt*1 (red dashed dotted line), *tt*2 (green dashed line) and *tt*3 (black dotted line).

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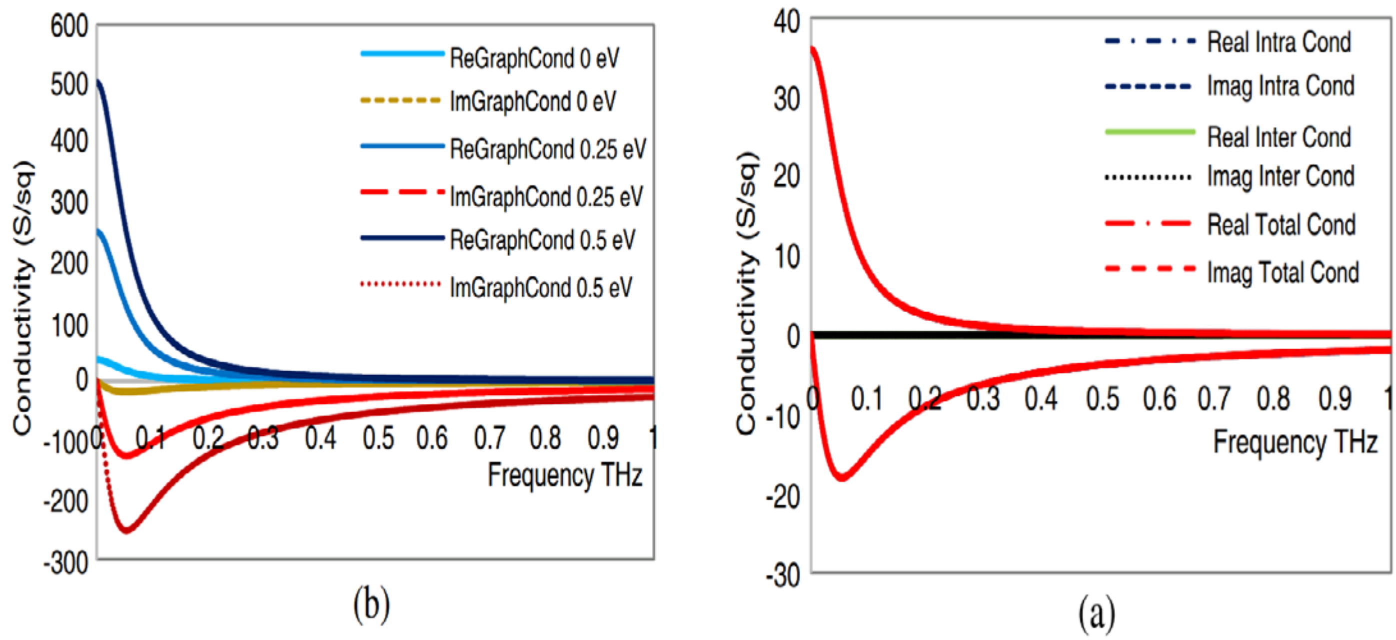

Figure 1. Conductivity of graphene, (a) intra, inter and total conductivity at 0 eV chemical potential, (b) real and imaginary graphene conductivity for different chemical potentials.

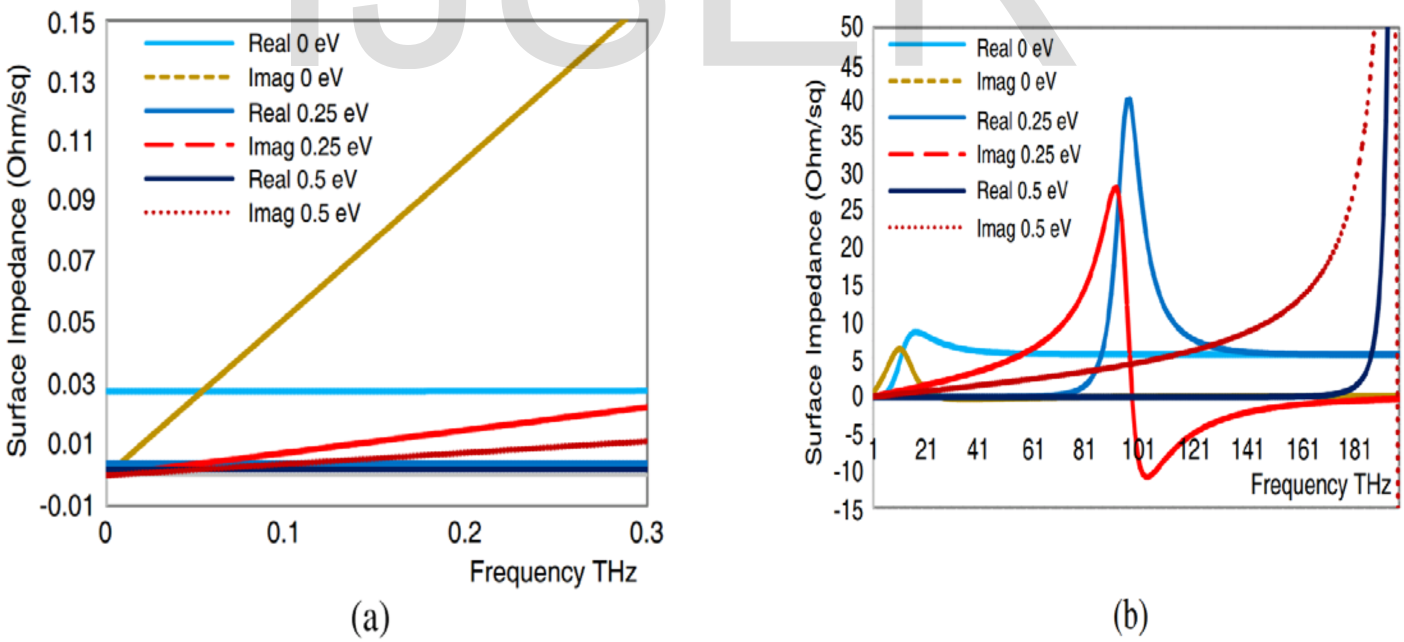

Figure 2. Calculated surface impedance of graphene, (a) in mm-wave band, (b) in THz and infrared band.

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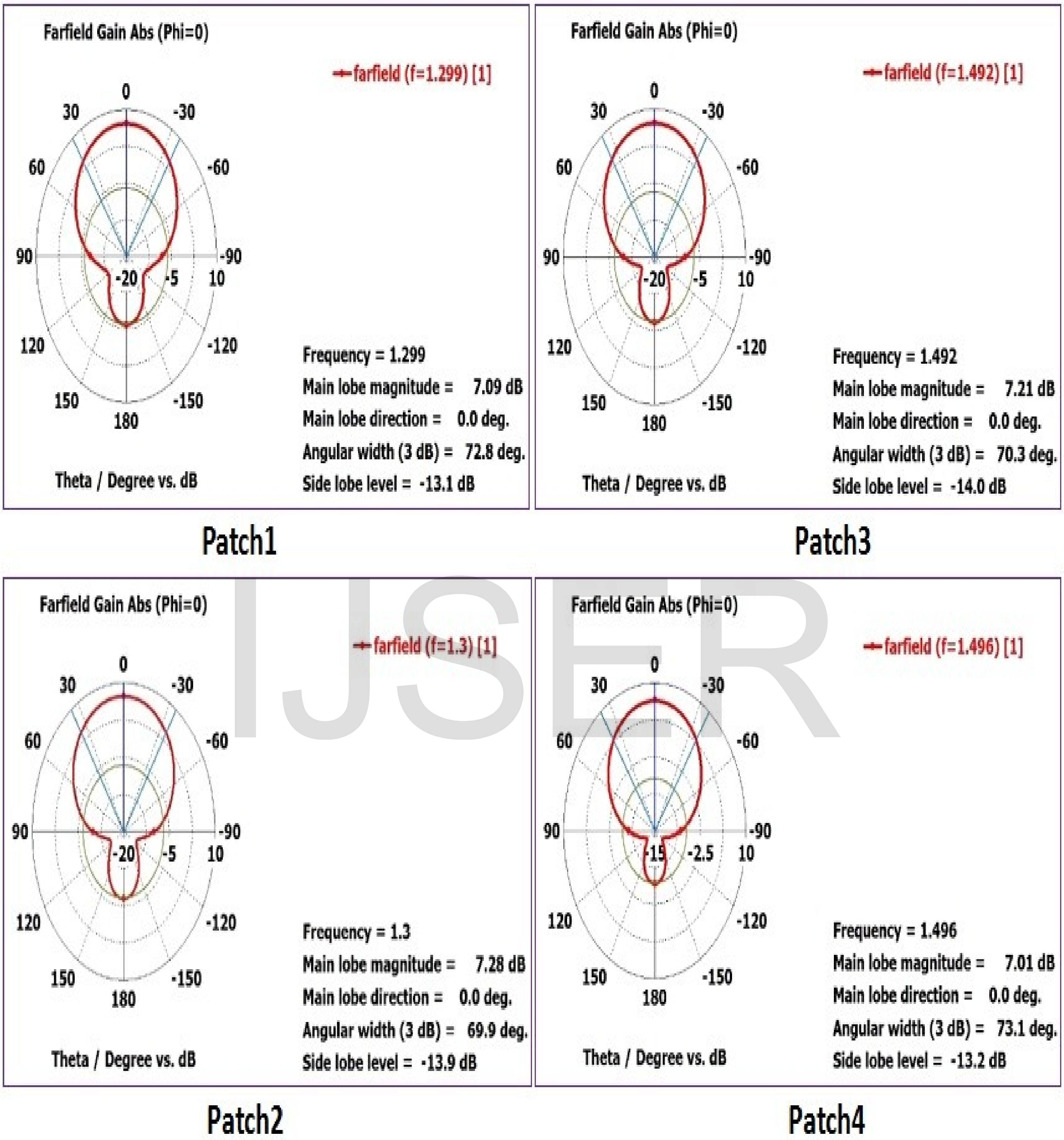

Figure 6. The far field radiation pattern of the four proposed doped graphene patch antennas: Elliptical patches (Patch-2 and Patch-3) features higher main lobe than that of rectangular patches at both frequencies.

4 Conclusions

The modeling and characterization of graphene-based antennas operating in the millimeter-wave and Terahertz bands have been presented. The modeling starts by numerically determining the surface impedance for a thin graphene layer using the Kubo formula. Next, these values are validated against two graphene-based microstrip antennas with different radiator topologies. The performance of the two antennas is determined by modeling and benchmarking them against their corresponding topology made using copper conductors in a commercial electromagnetic solver, CST Microwave Studio. The effect of different chemical potentials on the performance of both antennas is then studied by determining their surface properties (conductivities and impedances) prior to implementation and evaluation on these antennas. It is observed that the performance of the antenna with doped graphene as conducting elements indicates good improvements in terms of reflection coefficient, radiation efficiency, directivity and gain. For rectangular and elliptical antennas designed to resonate at two different frequencies(1.291 THz and 1.488 THz), the latter consistently indicates better performance than the former. The gain and radiation efficiency improvements for the graphene-based elliptical patches when biased using small levels of voltages (*tt*1 and *tt*2) are also relatively higher than the prototype with copper conducting elements. Besides higher gain and radiation efficiency, it is also demonstrated that biasing enables the graphene-based antennas' resonance tuneability. Thus we have seen that performance of novel 'GPA' is more in comparision to conventional patch antenna which is metallic.

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