Plasmonic high gain graphene-based antenna array design for ultra wide band terahertz applications

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Article Info

Article history:

Received Jun 28, 2022
Revised Jul 28, 2022
Accepted Aug 24, 2022

Keywords:

Antenna array
Graphene
Microstrip antenna
Surface plasmon polaritons
Terahertz antenna

ABSTRACT

Graphene, which consists of one atomic slide made from the Carbon, and it utilized in various of the implementations like the chemical, the thermal, the mechanical, and the electrical. In this research article, a high gain plasmonic antenna array is proposed for the utilizations of the terahertz (THz) regime on the basis of the graphene material. Also, the surface plasmon polariton (SPP) waves phenomena which emerged at THz in graphene are demonstrated the suggested antenna is composed of (4*6) graphene patches and a graphene Nano ribbon feeder to excite the patches deposed on the lumina layer. The simulated antenna was designed and investigated via the utilizing of the CST software. The obtained outcomes show that the antenna operation frequency bands covered a large band at the 2.6-10, 2.28-2.5, 1.87-2.14, and 1.4-1.6 THz with an S11 ≤ -10 dB and an expedient antenna gain in the operating frequency ranges.

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1. INTRODUCTION

The fully occupied frequency spectrum in the GHz frequency spectrum and the requirement for an extra bandwidth forced the discovery of a new unused frequency spectrum at THz. The highest data rate of the THz banis d is equal to 1 terabit-per second [1], [2]. Lay in the region (0.1–10) THz between millimeter and far-infrared (IR) waves [3]. THz spectroscopy and imaging have increased considerably in the past decade. The metals, like, gold, which are utilized in antenna manufacturing in the THz frequency range have good conductivity but it decreases in the THz range and leads to minimizing the antenna radiation efficiency in this range [4], [5]. To reduce the losses in THz antennas, the metals are not suitable to be used, so the superconductivity of the graphene can be utilized.

Because of its one-of-a-kind properties and numerous advantages, graphene has garnered significantly more attention than any other complex material. The material known as graphene is composed of a single layer of carbon atoms arranged in a two-dimensional structure in the form of a hexagon [6]. Graphene is utilized in different fields such as the mechanical, the thermal, and the electrical implementations [7]. The graphene electrica conductivity is controlled to be increased or decreased according to the applied DC voltage [8], photonic antennas based on graphene were also proposed in [9]. Due to its properties, graphene used in many application such as oscillators [10], reconfigurable optoelectronic devices [11], polymer waveguide [12], absorbers [13]-[15], optical antenna [16], antennas [17], [18], and medical applications [19], [20]. Also, graphene supports the surface plasmon (SP) wave at the beginning of the THz band [21]. The graphene is employed to create a high performance antennas, to be as the radiating elements in the antennas [22], [23], or artificial magnetic conductors (AMC) [24]-[26]. In this article ultra wide band (UWB) antenna based on graphene, the array is proposed at THz regime. The proposed antenna is composed of 24 graphpatchesatch (6×4) deposed on the alumina layer and fed by a graphene transmission line nanoribbon.

Many of the sections are introduced in order to arrange this paper to be as follows: section 2, this section of the article is introduced to presents the method that is used to develop this work. Section 3, this section of the article is introduced to exhibit the outcomes that are reached after the simulation procedure is completed. Section 4, this section of the article is introduced to demonstrate the conclusion that has been reached from this work.

2. METHOD

2.1. Graphene modelling

A graphene-based antenna patch array designed by many researchers [27]-[31], but these antennas have lower gain. The proposed antenna in this paper has a high gain. The graphene surface conductivity consists of two portions, the primary portion is called the intra-band whidominatesate in the frequency < 5 THz, the second part is the intern-band whidominatesate at higher frequencies and it depends on frequency, chemical potential, scattering rate and, temperature. The mathematical model for the conductivity is given by [31], [32] as follows:

$$\sigma = \sigma_{intra} + \sigma_{inter} \tag{1}$$

$$\sigma_{intra}(\omega, \mu_c, \gamma, T) = \frac{e^2 k_B T \tau}{\pi \hbar^2} * \left[\frac{\mu c}{k_B T} + 2 * \ln\left(e^{\frac{-\mu c}{k_B T}} + 1\right)\right] * \frac{1}{\omega - j2\gamma} \tag{2}$$

$$\sigma_{inter}(\omega, \mu_c, \gamma, T) = \frac{-je^2}{4\pi h} * \ln\left(\frac{2*|\mu_c| - (\omega - j2\gamma)h}{2*|\mu_c| + (\omega - j2\gamma)h}\right) \tag{3}$$

$$\mu_c = \upsilon_f \hbar \sqrt{n\pi} \tag{4}$$

$$n = \frac{\varepsilon_o * \varepsilon * V_b}{d * q} \tag{5}$$

The dispersion equation for SPP is can be written as follows:

$$\sqrt{n^2 - n_{eff}^2} + n^2\sqrt{n^2 - n_{eff}^2} + \frac{4\pi}{c}\sqrt{1 - n_{eff}^2}\sqrt{n^2 - n_{eff}^2} = 0 \tag{6}$$

$$(kSPP = neff \times \omega/c) \tag{7}$$

It is possible to give a mathematical representation for the surface impedance of the graphene material, to be as follows:

$$Z_S = \sigma(\omega)^{-1} = R_S + j X_S \tag{8}$$

$$k_{SPP} = 2\pi/\lambda 0 * (n_{eff}) \tag{9}$$

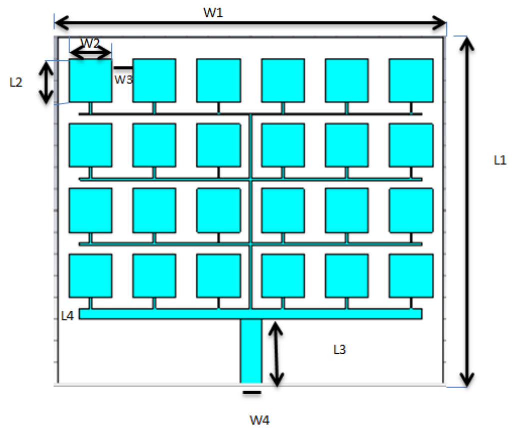
The description and definition for the parameters/constants that are utilized in the paperare presented in Table 1.

2.2. Proposed antenna

The introduced antenna has been simulated and analyzed by the means of the CST software. The arallel feed approach of the array is employed because it allows for the most effective impedance coupling and ensures that the electrical power that is supplied by the source will be distributed evenly. The antenna is composed of 6×4 graphene patches connected by graphene nanoribbon deposed on a 3 um layer of alumina. A crystallin silicone layer of 2 um under the alumina layer and a grounded 10 um layer of silicon dioxide. The antenna is fed by a 50 Ω wave port, Figure 1(a) and Figure 1(b) illustrates the configuration for the proposed antenna in two dimensions and 3 dimensions respectively. Table 2 clearly described the overall dimensions for the simulated antenna in (μm).

Table 1. Definition and the units of the used parameters

Parameter	Description	Units
ω	Angular frequency	Rad/s
γ	Scattering rate	1/s
μ_c	Chemical potential =1	ev
T	Temperature =300	Kelvin
e	Electron charge = 1.60217662×10^{-19}	coulombs
$\hbar$	Reduced Planck's constant= $1.054\ 571\ 817...\times10^{-34}$	J s
k_B	Boltzmann constant = 1.38064852×10^{-23}	$m^2\ kg\ s^{-2}\ K^{-1}$
v_f	Graphene Fermi velocity = 2.5×10^6	m/s
ε_o	vacuum permittivity	F/m
ε	Dielectric relative permittivity	
V_b	DC applied voltage	V
d	Thickness	m
n_{eff}	complex propagation index	
n	refraction index	
k_{SPP}	complex propagation constant	
k_0	free space wave number	



(a)

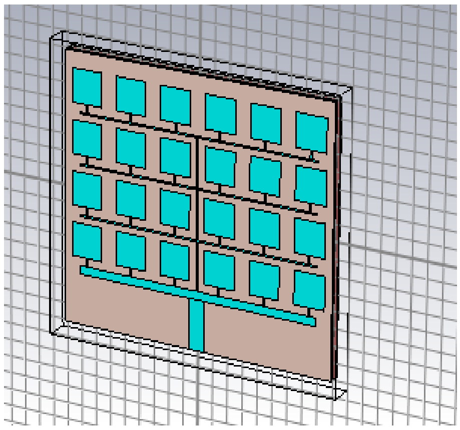

(b)

Figure 1. Schema for the introduced antenna array (a) 2D view and (b) 3D view

Table 2. Dimension of the introduced antenna array

W_1	L_1	W_2	L_2	W_3	L_3	W_4	L_4
360	320	40	40	20	60	20	10

3. RESULTS AND DISCUSSION

The proposed antenna array consists of 4×6 graphene patches deposed on 3 µm of alumina, the graphene layers height is considered to be equals 1 nm. The silicone crystals are placed under the alumina layer with a height of 2 µm. The grounded substrate of the antenna is selected from the SiO_2 material with a ε_r=3.9 and a thickness of 10 µm placed under the silicone crystalline layer. The antenna was simulated by using CST 2020 package. The return loss graph for the antenna at $\mu_c = 1$ is exhibted in Figure 2.

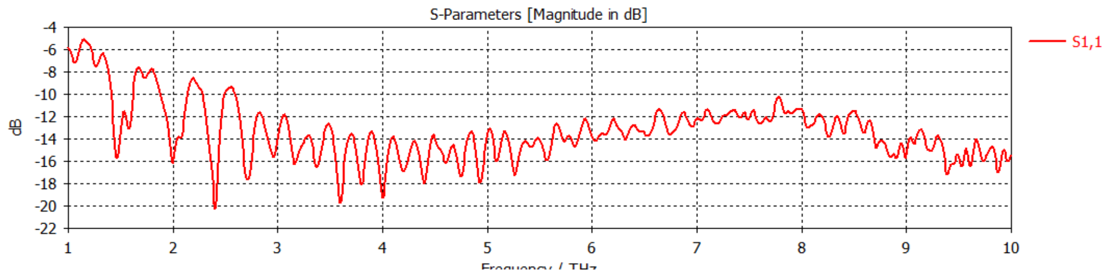


Figure 2. Return loss results for the simulated antenna

From the previous Figure 2 it is clearly present that the proposed antenna has a multibands of frequency which are (2.6-10), (2.28-2.5), (1.87-2.14), and (1.4-1.6) THz where S_{11} less or equal -10 dB. The voltage standing wave ratio (VSWR) result is shown in Figure 3. It is clear from the figure that the antenna has VSWR less or equal to 2 at frequency (2.5-10) THz. The outcome for the antenna gains in the all-operation regime is exhibted in Figure 4; which is show that, the introduced antenna is characterized by sufficient and credible gain at the frequency bands (1-2.5) and (3.5-10) THz. Figures 5(a)-(f) (see in the Appendix) shows the 3D far-field radiation patterns at frequency (f=1,2,3,5.5,9, and 10) THz respectively.

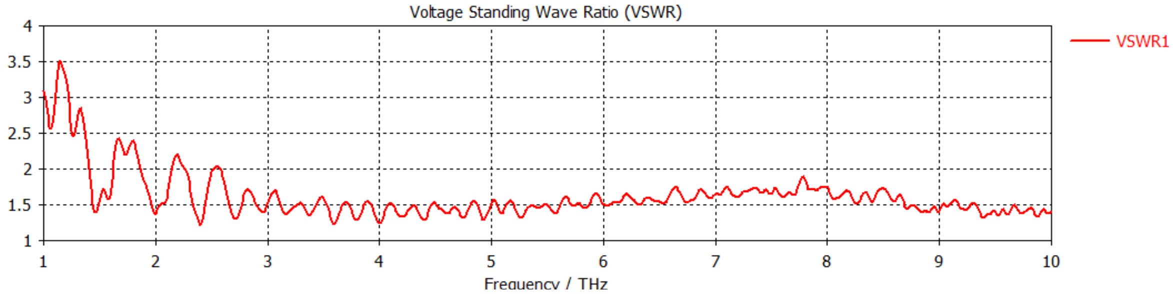


Figure 3. VSWR for the simulated antenna

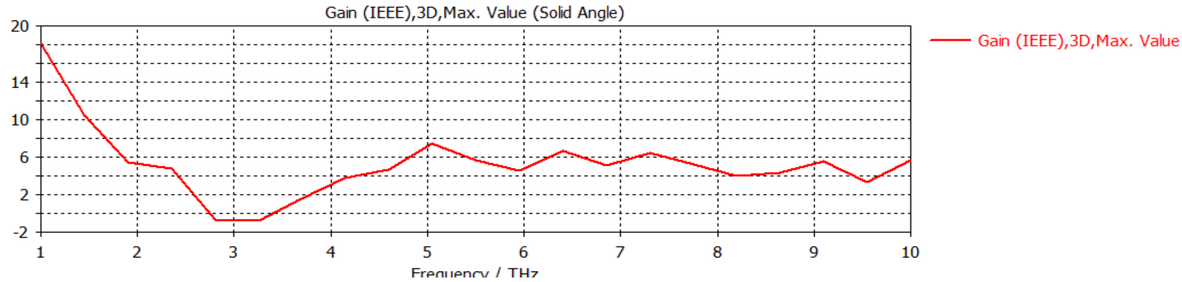
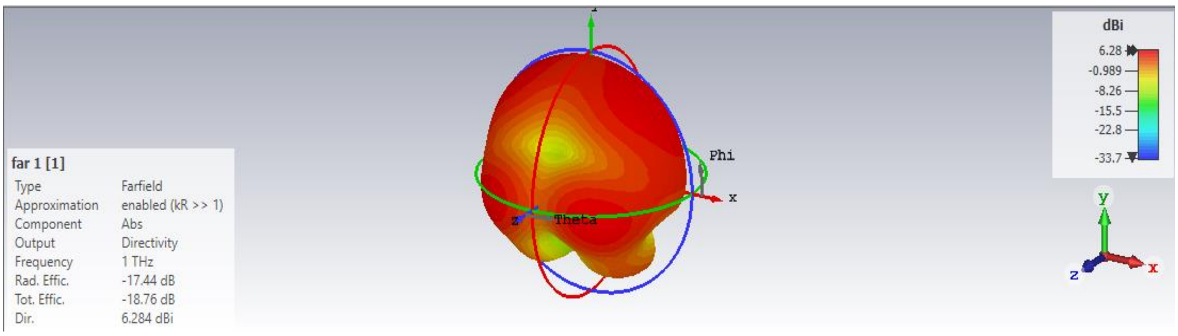


Figure 4. Plot for the gain versus frequency of the antenna

4. CONCLUSION

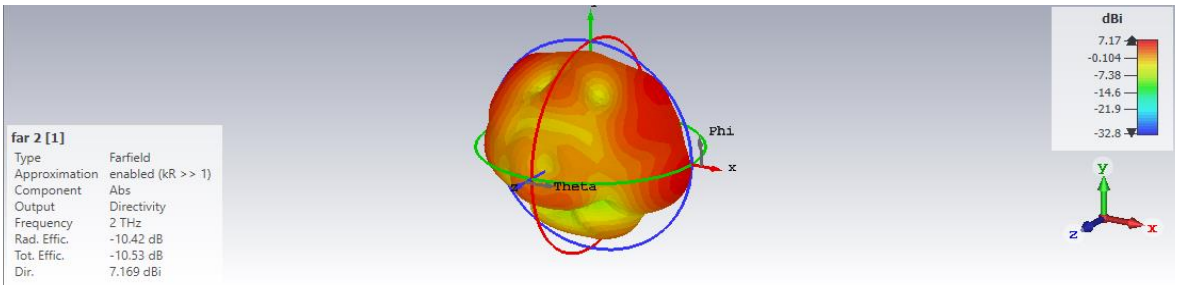
A plasmonic antenna array based on graphene material was designed and analyzed. Graphene's chemical potential can be modified according to the applied electric field and this yields to change in the characteristic of the graphene. The results that have been obtained from the software demonstrated that the introduced antenna has low return losses and the VSWR is also low less or equal to 2 and the antenna has high gain in the designed frequency band. A plasmonic phenomenon appeared in graphene at the THz regime.

APPENDIX

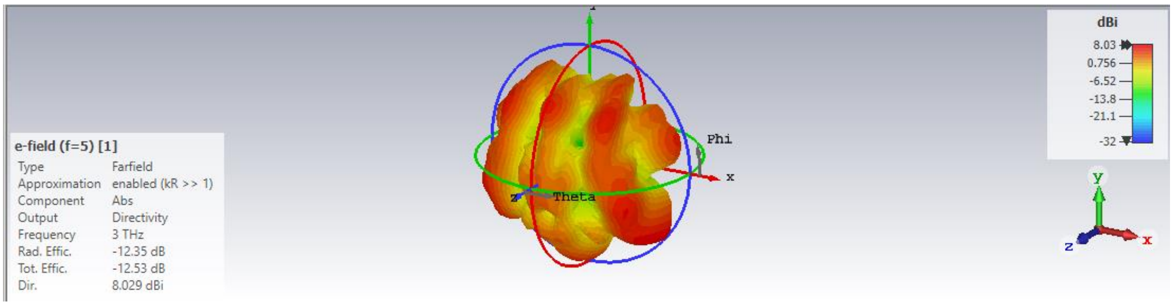


(a)

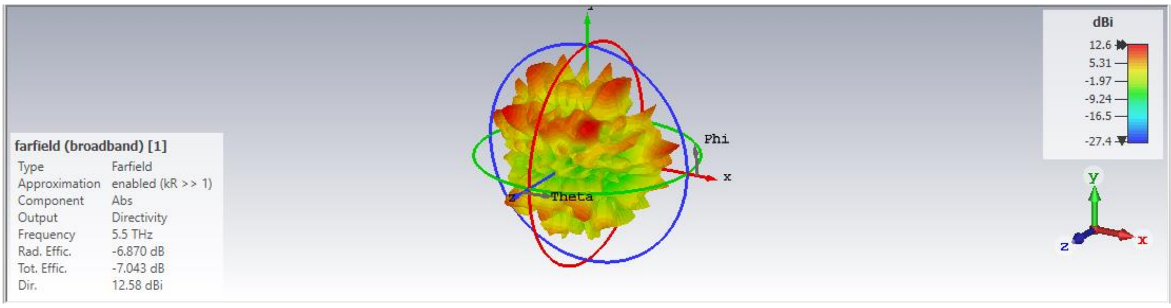
Figure 5. The 3D gain for the simulated antenna (a) f=1 THz



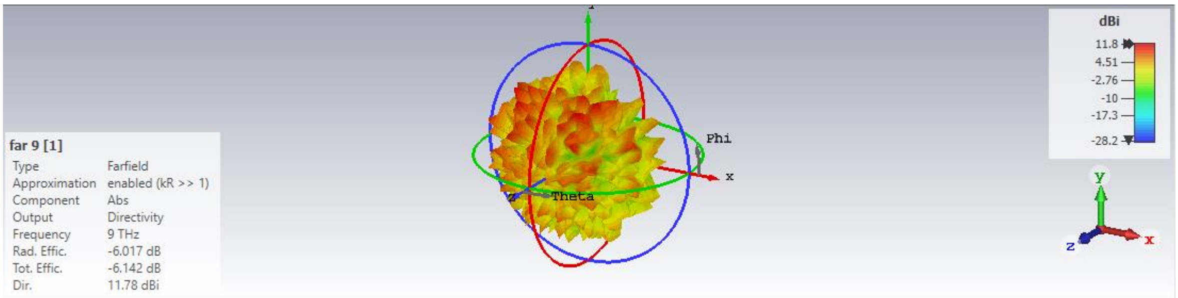
(b)



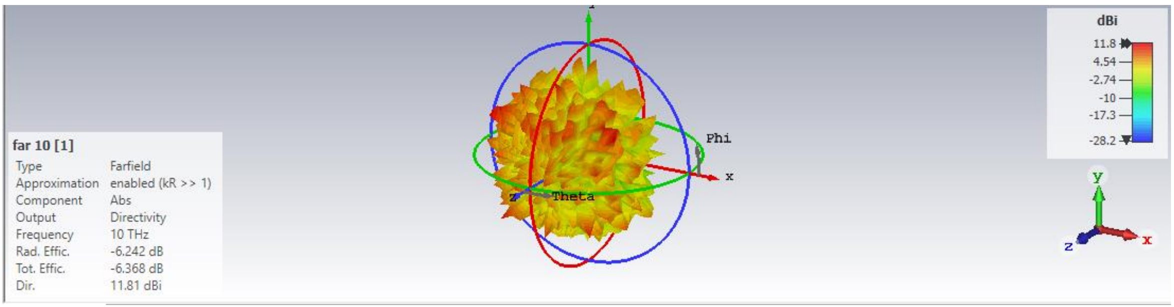
(c)



(d)



(e)



(f)

Figure 5. The 3D gain for the simulated antenna (b) f=2 THz, (c) f=3 THz, (d) f=5,5 THz, (e) f=9 THz, and (f) f=10 THz (continue)

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