Toothed log periodic graphene-based antenna design for THz applications

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ABSTRACT

This paper proposes a graphene-based toothed log-periodic antenna for the THz frequency region (0.1–10) THz applications. By adjusting the applied DC voltage on the graphene, the antenna's properties, such as bandwidth, radiation pattern operational frequency ranges have been shifted. The chemical potential, surface conductivity, and surface impedance of the graphene are affected by changing applied DC voltage and hence a reconfigurable antenna has been resulting. The suggested antenna's radiating element is from a graphene material and has log-periodic shape, with 50 ohm feed line placed on the grounded silicon dioxide substrate, 1 µm-thick layers of silicon crystalline and alumina on top of the substrate. The antenna is simulated by the computer simulation technology (CST) 2020 software program. The resultant bandwidth (7-10) TH has a return loss of less than -10 when the chemical potential of graphene is 1eV.

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1. INTRODUCTION

Wireless data traffic has expanded significantly in recent years because of a shift in how humans generate, distribute, and consume information. This adjustment necessitates an increase in significantly faster wireless data transfer rates at all locations. Transmission of information have increased and doubled every one and half years in the past three decades and are rapidly approaching parity with wired communication networks [1]. As a result of this yields to, wireless (Tbps (terabits/second)) connections are anticipated to become commonplace. Terahertz (THz) frequency band was spurred by the need for greater bandwidth and the fully utilizing of spectrum in (GHz) frequency range. The greater bandwidth of the THz band enables future wireless devices to attain a large data throughput, such as one terabit per second [2]. The terahertz band ranges from 0.1 to 10 THz. The mid-infrared spectrum, on the other hand, is the frequency band before the far-infrared and after microwaves [3]. THz applications such as spectroscopy, imaging, and other applications have advanced dramatically in recent times. THz-frequency antennas are typically fabricated using metals, such as gold. Compared to its DC conductivity, the metal's conductivity decreases at THz frequencies, resulting in more penetration into the metal. This metal property reduces the radiation effectiveness of metallic antennas at THz frequencies [4]. Small antennas have a substantially reduced radiation efficiency at 1 THz [5] due to the high surface resistance of metallic traces, as determined by computer research. This reduced conductivity results from grain boundary scattering, surface scattering, and surface roughness [6], [7]. These variables can substantially affect the estimated radiation efficiency of THz-band and higher antennas. In addition, the fabrication and gold deposition processes necessary to create thin layers with a trace width of less than 100 nm result in conductivity values that are considerably lower than those of the bulk material. Non-metallic materials should be researched to reduce losses in small-scale antennas. Graphene is the current material used to decrease losses in the THz region [8]. Numerous thermal, mechanical, and electrical applications use graphene, a single atomic carbon layer. Single-walled carbon nanotubes are another form of graphene [9], [10]. Numerous graphene devices, including polarizers, filters, absorbers, and antennas, have been proposed for THz, MW, and optical frequency ranges [11] because the surface conductivity of graphene may be altered by modifying the electrical DC bias. In addition, graphene THz photonic antennas were suggested in [12]. Graphene is exploited in the design of THz antennas as a radiating patch [13], parasitic component or high impedance surfaces (HIS), and a shape [14]. This study proposes a novel graphene-based log periodic antenna with frequency tuning in the terahertz band. The DC voltage changes the graphene's conductivity, tuning the antenna and expanding its bandwidth. Many methods used to enhance the bandwidth, such as using meta-material [15], modifying patch antenna [16]

2. METHOD

2.1. Graphene conductivity

Due to its atomic thickness, graphene exhibits exceptional electrical characteristics as a two-dimensional material. Chemical potential, relaxation time, and frequency influence the surface conductivity of single-layer graphene. The value of graphene's dispersive characteristics can be altered by adjusting the frequency and other parameters [17], [18]. The surface conductivity of graphene σ (**ω**, T, **μ**c, *Γ*) is described using Kubo Forma [19]. It is divided into two sections: inter-band and intra-band. At lower frequencies, the intra-band predominates, whereas the inter-band predominates at higher frequencies. The model's accuracy is equivalent to the sum of the conductivity's two components [20], [21].

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

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

$$\sigma_{intra}(\omega, T, \mu_c, \gamma) = \frac{e^2 k_B T \tau}{\pi \hbar^2}\left[\frac{\mu c}{k_B T} + 2\, ln\left(e^{\frac{-\mu_c}{k_{BT}}} + 1\right)\right]\frac{1}{\omega - j2\gamma} \quad (3)$$

Where γ is the scattering rate, ħ is the reduced Planck's constant, μc is the chemical potential (eV), ω denotes frequency in rad/s, T mean temperature (K), k_B is the boltzmann constant, and e is electron charge. The chemical potential μc is determined by the carrier density n (m^{-2}).

$$\mu c = \nu f\ \hbar\sqrt{n\ \pi} \quad (4)$$

where υf=1x106 denotes the graphene's Fermi velocity. The electric field effect can be used to change the value of n.

$$n = \frac{\varepsilon o \varepsilon Vb}{dq} \quad (5)$$

Vb is the bias voltage, d is the dielectric material height in millimeters, and ε represents the free space permittivity (F/m) (where ε the relative permittivity of the dielectric material between the back gate material and the graphene sheet). The dispersion equation for the SPP can be found in (6):

$$\sqrt{n^{\,2} - n^2 eff} + n^2\sqrt{n^{\,2} - n^2 eff} + \frac{4\pi}{c}\sigma w\sqrt{1 - n^2 eff}\sqrt{n^{\,2} - n^2 eff} = 0 \quad (6)$$

where n denotes to the refraction index of substrate, neff=complex propagation index, n, kSPP=neff×ω/c. The SPP wave's propagation constant is provided by [22]:

$$kSPP = k0(neff) \quad (7)$$

where neff mean the SPP modes' complex effective index, and k0=2π/λ0 equal to the free space wavenumber. The resonant length L1 is half the surface plasmon polariton's wavelength λSPP.

$$\lambda_{spp} = \frac{2*\pi}{Re(k_{spp})} \quad (8)$$

The graphene's surface impedance can be determined [23]

$$Z = \frac{1}{\sigma(\omega)} = R + jX \tag{9}$$

2.2. Toothed log periodic antenna design

Figure 1 depicts the log-periodic antenna (TLPA) with teeth. This antenna is frequency independent, with a bandwidth greater than 10:1. The geometrical characteristics of the antenna sectors must be logarithmically scaled to provide a homogeneous radiation behaviour throughout the broad bandwidth. The word "log-periodic" refers to the regular spacing between an antenna's resonance frequencies on a logarithmic scale [24]. The first log-periodic planar antenna, as depicted in Figure 1, consisted of circularly curved teeth of variable lengths [25]. Periodically, the ratio between the size of each tooth and its distance from the centre increases:

$$Ş = \frac{R_n}{R_{n+1}} \tag{10}$$

Therefore, indicates the ratio of two neighboring resonance frequencies as follows:

$$Ş = \frac{f_1}{f_2} \qquad f_2 > f_1 \tag{11}$$

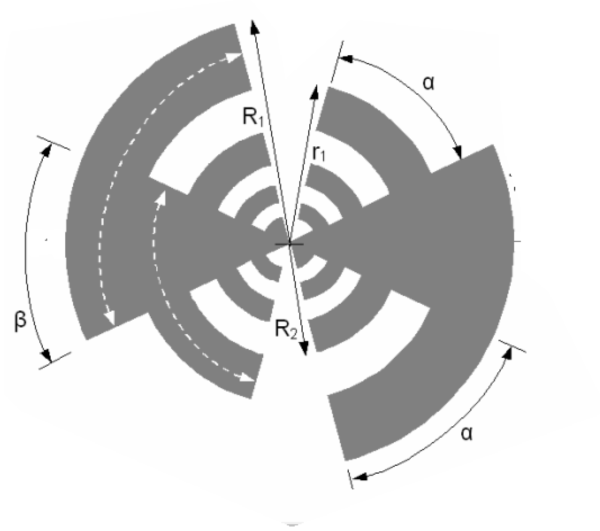


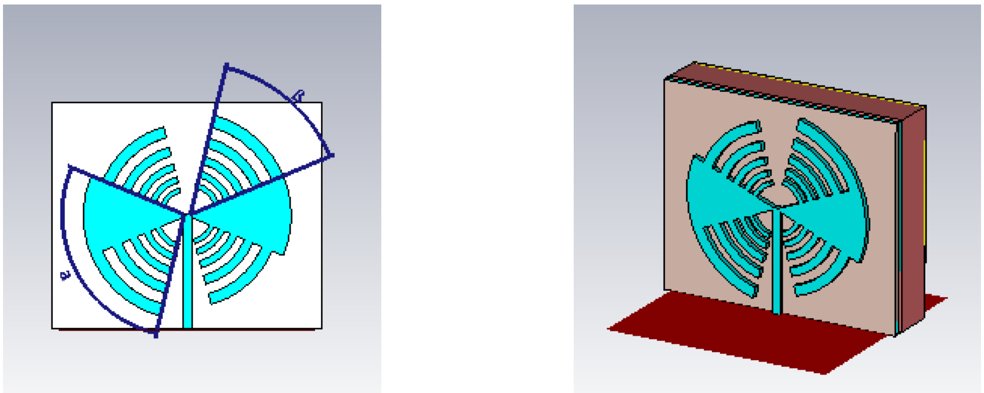
Figure1. Toothed log periodic antenna

To achieve consistent radiation performance, (the expansion ratio) must be made sufficiently minimal. The resonance frequency h is dictated by the size of the minor teeth, whereas the size of the enormous teeth determines the operating frequency f_l. Depending on its size, each tooth has a resonance frequency between fh and fl. To prevent lower-order modes of the enormous teeth from radiating low-frequency information, the LP antenna is fed from the high-frequency end.

3. RESULTS AND DISCUSSION

The geometry of the antenna model is depicted in Figure 2. Figure 2(a) illustrate the proposed antenna in front view, while Figure 2(b) shows the 3-D structure of the antenna by using CST software. The suggested antenna is printed onto a silicon dioxide substrate, and there are two 1 µm-thick layers of silicon crystalline and alumina on top of the substrate. The ground is made of copper. The patch is log toothed periodic made from graphene the proposed antenna has a parameter of α=67 and β=45, where α and β are angles shown in Figure 2(b) τ=0.9, R=17 µm.

Using CST Studio version 2020, simulation results for the proposed antenna are generated for various chemical potential values. The outcomes of S11 concerning µc are provided. Figure 3 depicts the scattering parameter S_{11} in decibels for µc=(0.1-1) Ve for the proposed antenna. Table 1 illustrates the operational bandwidth at which S_{11}<-10 dB is seen, while Figure 4 shows the antenna gain and its (1.2-6.5) dB. The Figures 5-8 show the radiation pattern of the frequencies (2, 3, 6, 9) THz, respectively.



(a) (b)

Figure 2. the proposed antenna(a) front view and (b) 3-D structure

Table 1. The resonant frequency of the proposed antenna at µc=(0.1-1)Ve

Chemical Potential µc	Resonant Frequency in THz
0.1	8.5
0.3	0.18,0.81,5.6
0.5	0.23,1,2.2,7.2,9.9
0.7	2.6,3.7,7,4,8.7
1	2.5,3,4.4,5.1,5.6,7.4,9.1

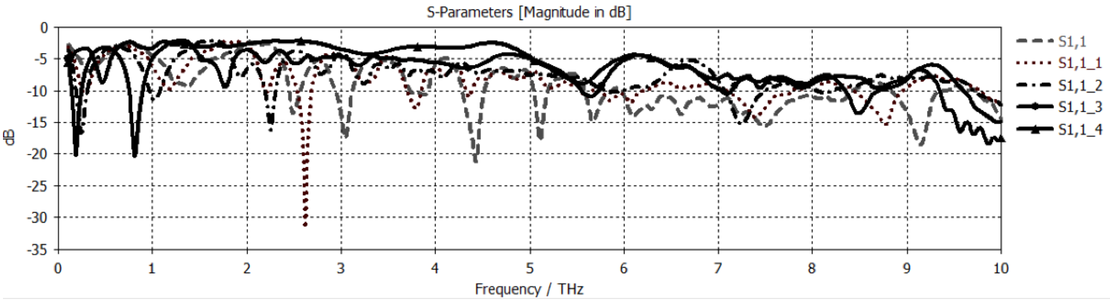


Figure 3. Return losses S_{11} at µc=(0.1,0.3,0.5,0.7,1)

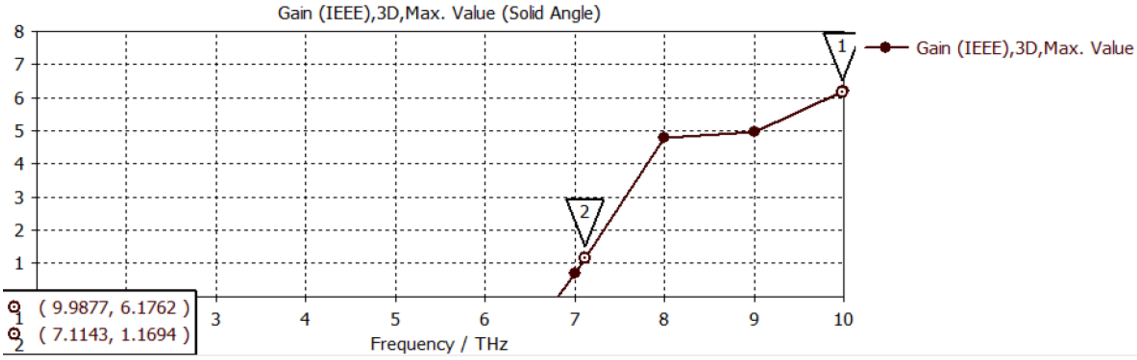


Figure 4. Gain of proposed antenna at µc=1

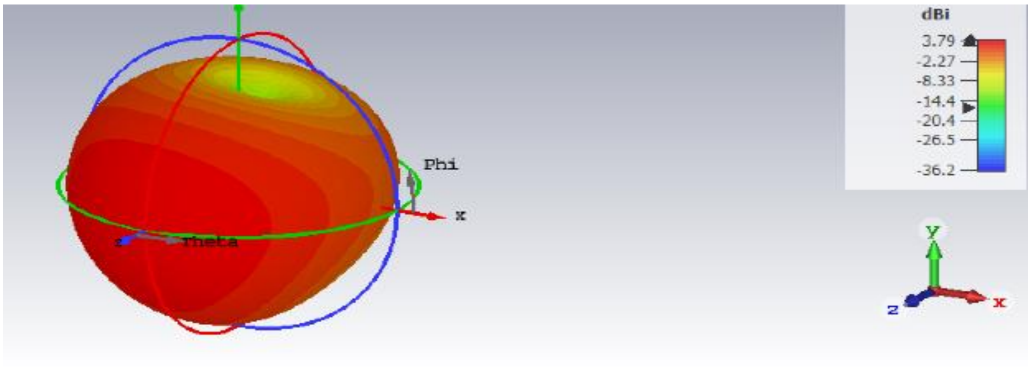


Figure 5. Radiation pattern at 2 THz

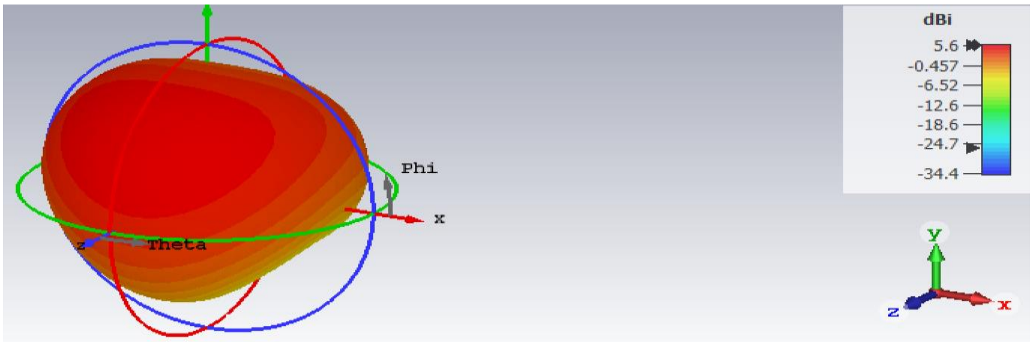


Figure 6. Radiation pattern at 3 THz

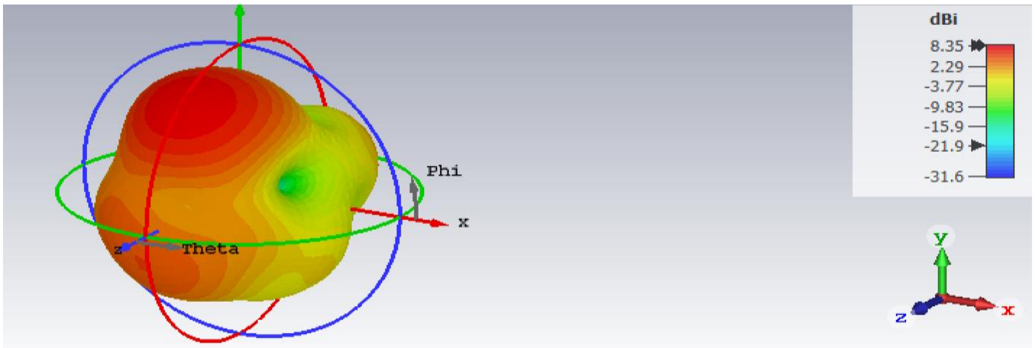


Figure 7. Radiation pattern at 6 THz

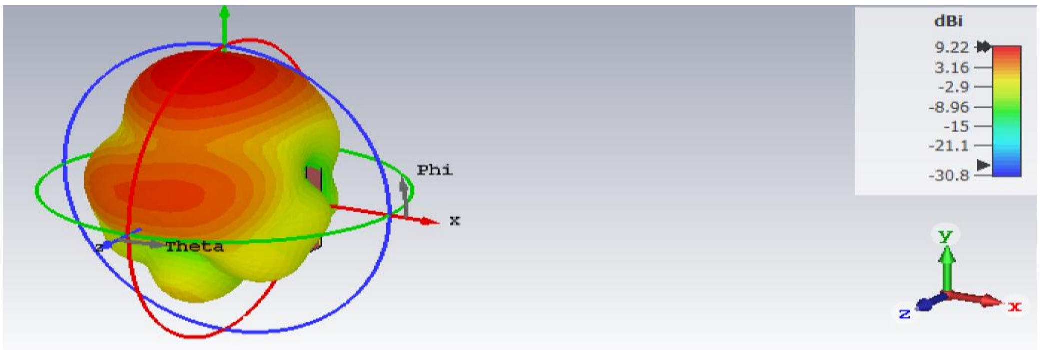


Figure 8. Radiation pattern at 9 THz

4. CONCLUSION

In this study, a graphene-based antenna capable of S11 -10 dB at the UWB operating frequency band (0.1–10 THz) was constructed. The antenna itself is a log periodic antenna with teeth made from graphene material. The simulation results were achieved by modifying the chemical potential values in CST Studio version 2020. The suggested antenna's maximum bandwidth is between 7 and 10 THz. Additionally, it features a gain of 6 dB for the 7-10 THz frequency region.

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