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(Review Article)

Investigating the impact of graphene patch width on performance and bandwidth enhancement in nano-patch antennas

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Abstract

This study investigates how varying the width of a graphene patch affects the performance and bandwidth of a nano-patch antenna. High-Frequency Structural Simulator (HFSS) software was employed for simulation, evaluating parameters such as voltage standing wave ratio (VSWR), gain, and return loss. The graphene patch of 0.690nm thick was placed on a silicon dioxide substrate with a thickness of 10 µm, while the patch width was systematically varied at 30 µm, 32 µm, 34 µm, 38 µm, and 42 µm. Surprisingly, the resonating frequency remained unaffected by changes in patch width. The results revealed that the patch widths of 32 µm, 34 µm, and 38 µm produced the highest return losses of -24.5482, -24.4774, and -24.4001, respectively. Additionally, these configurations exhibited impeccable VSWR values of 1.0302, 1.0387, and 1.0480. Notably, a substantial bandwidth improvement exceeding 500 GHz was achieved for these patch widths. This finding underscores the significant relationship between gain, directivity, and patch width in graphene nano-patch antennas. Furthermore, both 32 µm and 34 µm patch widths demonstrated gain and directivity exceeding 7 dB.

Keywords: Bandwidth; Gain; Graphene; Directivity; Nano-patch

1. Introduction

Electromagnetic nano-communication has recently attracted substantial research attention, primarily because of the emergence of new materials such as carbon nanotubes (CNT) [1] and graphene [2]. These new materials have good electrical and mechanical properties in the terahertz (THz) frequency band and are capable of miniaturization and antenna tunability [3]. The THz band comprises frequencies ranging from 100 GHz to 10 THz, which are directly above and below the microwave and optical bands. Propagation in the THz band differs from microwave and optical propagation owing to the high molecular absorption and scattering upon reflection [4]. Spontaneous behavior, which is a peculiarity of the THz band, must be considered in the design of electromagnetic nano-communication systems. The low efficiency, narrow bandwidth, and lower gain of microstrip antennas are major operational drawbacks. To boost the bandwidth and gain of the microstrip patch antenna, strategies such as increasing the substrate thickness or patch size have been used. However, a thicker substrate reduces the radiation efficiency owing to greater surface wave losses. Because it can limit surface wave propagation and improve the electrical performance of the microstrip patch antenna, photonic crystals are non-natural materials made of periodic implant structures within the surrounding medium, which might be dielectric or conductor. The scattering and diffraction properties of periodic structures significantly affect their electromagnetic wave propagation. Thus, antennas with photonic crystals exhibit many unique characteristics [5, 6, and

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7]. Graphene has received attention seriously in various research areas due to its exceptional electrical and mechanical properties [8]. Graphene is a hexagonally organized honeycomb lattice material with a high mobility (8000 cm2/V), 5000W/m/K thermal conductivity, and observable flexibility [9, 10, 11]. In general, the conductivity of graphene is very frequency dependent and can exhibit different behaviors, for example, at microwave and THz, as shown in figure 1. Currently, graphene has gained a lot of attention as a material and has various uses in the microwave to millimeter wave range [12.13]. However, the application of graphene in passive-guided devices and antennas from microwaves to THz has been less exploited.

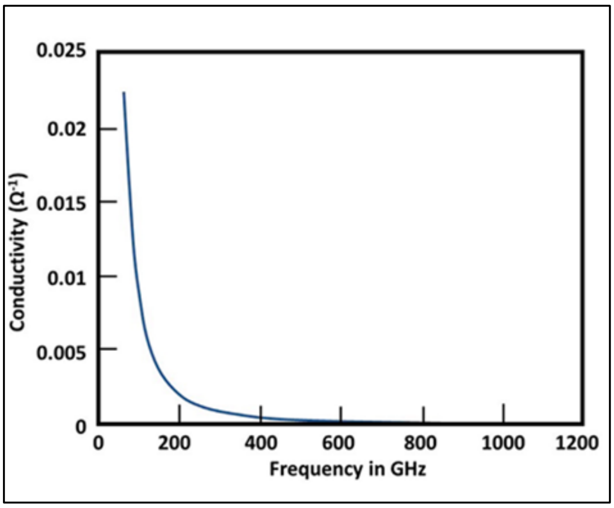

Figure 1 Graphene's conductivity VS frequency graph as presented by Kubo's formula [14]

The use of graphene as a conducting substance for the patch is speculated to enhance the bandwidth and radiation efficiency of the antenna owing to its standout functionalities and electromagnetic properties. Several studies have been published using graphene as antennas, filters, amplifiers, and other telecommunication devices.

2. Review of Related Works

The radiation properties of a copper-patch antenna designed for resonating at the frequency of 0.7 THz, which is used in aerospace applications, were presented [15]. These properties were then compared to those of a graphene patch antenna with the same dimensions. Their work shows how the use of graphene as a tunable material allows dynamic modification of the frequency of operation of the antenna as well as its radiation pattern. The results further show that the return loss peak reaches 29 dB at the operating frequency, which is almost twice the value obtained using the copper patch. This increase in the return loss peak is also accompanied by an improvement in the gain of the antenna from 5.73 dB in the case of the copper patch to 7.16 dB in the case of graphene. However, the bandwidth issue was not taken into consideration in their work. Similarly, [16] designed a plasmonic nano-patch antenna on the graphene material with the conductivity of the graphene material modelled using the Kubo conductivity formula and it was tuned using the chemical potential of graphene. The designed graphene nano-patch antenna provides a gain of 3.52 dB at a 30 THz frequency, which is suitable for terahertz communication. It was shown that the graphene nano-patch antenna resonates at multiple frequencies by varying the chemical potential. Three resonating frequencies of 30, 115, and 176 THz were observed at a 1.3 eV chemical potential. The gain of the graphene nano-patch antenna was enhanced by approximately three times by changing the shape of the patch from square to L-shape; however, this result shows that their working frequency was above the stipulated THz frequency of (0.1-10 THz). [17] Provided a simple model for a graphene-based nanopatch antenna, which they used to characterize the antenna by means of simulation. Their result confirmed that a graphene-based nano-patch antenna with dimensions of a few micrometers resonated in the terahertz band, which is consistent with the theoretical model. Moreover, the dependence of the antenna resonant frequency on the dimensions of both the graphene patch and the dielectric substrate was observed. However, the radiation pattern of a graphene-based nano-patch antenna was found to be very similar to that of an equivalent metallic antenna. In [18], the authors analyzed the radiation scattering on a rectangular graphene-based nano-patch antenna due to the propagation of surface Plasmon polariton waves in graphene. The antenna exhibited resonant behavior in the terahertz frequency band. The simulation results show that a structured graphene film has the potential to be used as a tunable terahertz antenna. They observed that the antenna resonant frequency can be tuned by changing the substrate material or size or by applying an external electrostatic bias. However, this antenna-tuning method is complex. In a similar manner, [19] presented a pentagon-shaped plasmonic graphene nanopatch antenna designed and investigated on silicon dioxide, silicon nitride, and zinc oxide substrates. The optical characteristics of graphene, such as conductivity and permittivity, were analyzed at various values of the chemical potential using the Kubo conductivity model. The plasmonic resonance of the proposed nano-antenna was analyzed by varying the graphene chemical potential in the span of 0.0 eV to 2.0 eV. They observed that the proposed pentagon-shaped graphene nano-patch antenna exhibited good plasmonic resonance characteristics at 29.8750 THz with a reflection coefficient of -27.4153 dB, 91.5650 THz with -27.5179 dB, and 853.7350 THz with -40.3267 dB on silicon dioxide, zinc oxide, and silicon nitride substrates, respectively. These optimum characteristics are observed at the chemical potential values 2.00 eV and 0.50 eV for the proposed graphene nano-patch antenna. However, their work didn't consider the bandwidth, VSWR, or gain of the antenna. In this work, we will consider the gain, bandwidth, VSWR and return loss for the analysis of the graphene based patch antenna.

3. Tunability Attributes of Graphene

The tunable antenna is designed such that the resonant frequency, operational bandwidth, radiation pattern, and/or polarization can be changed manually or automatically (via software) to adapt to different services, system requirements, and environments. These procedures are generally performed using micro- or nano-electromechanical systems, microcontrollers, electrical Radio Frequency (RF) switches such as metal semiconductor field-effect transistors, and diode-based technologies such as P-type N-type insulator diodes, varactors, or tunable materials [20]. Alternatively, the tunable surface impedance of graphene can be used in reconfigurable antennas. Graphene, a combined carbon sheet arranged in a hexagonal lattice in two dimensions (2Ds), allows multifunctionality in terms of signal emission, transmission, modulation, and detection and features broadband, high-speed, compact size, and particularly low loss [21]. Graphene materials can be used in tunable antennas such that the conductivity of the surface is changed by applying an external electrical field to the graphene sheet. The graphene admittance is adjusted by applying a direct current (DC) voltage bias between the graphene sheet and the ground such that the ON and OFF states become high and low, respectively, as illustrated in Figure 2. This effect is used to vary the electrical dimensions of the antennas and thus change the resonant frequency, as desired. However, graphene is not limited to being an alternative to a conventional RF switch; it can also be used to fabricate the radiating antenna itself. Graphene-tunable antennas have been mostly studied in the infrared and terahertz frequencies, as graphene can significantly reduce the size of the antenna and provide high antenna reconfigurability. Tunability can be achieved in the following ways:.

- Varying geometric properties (length, width and thickness of patch)
- Varying chemical potential or DC bias voltage
- Using suitable substrate material

Tuning or varying the antenna performance by varying the patch dimensions is fundamentally the antenna design process. Therefore, initially the analysis is performed for varying length, width and thickness of the graphene patch.

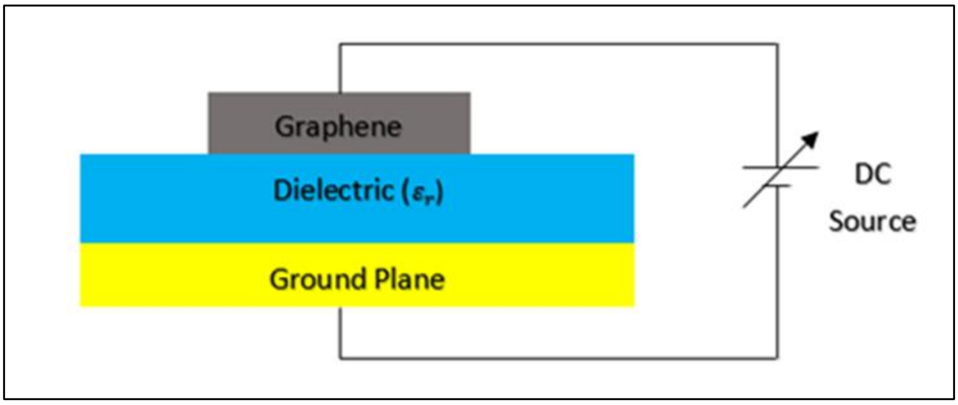

Figure 2 Varying direct current (DC) voltage bias between the graphene sheet and the ground

4. Design requirements

The High Frequency Simulator Structure (HFSS) model is created with patch dimensions of 30 × 22 µm, as shown in Figure 3.

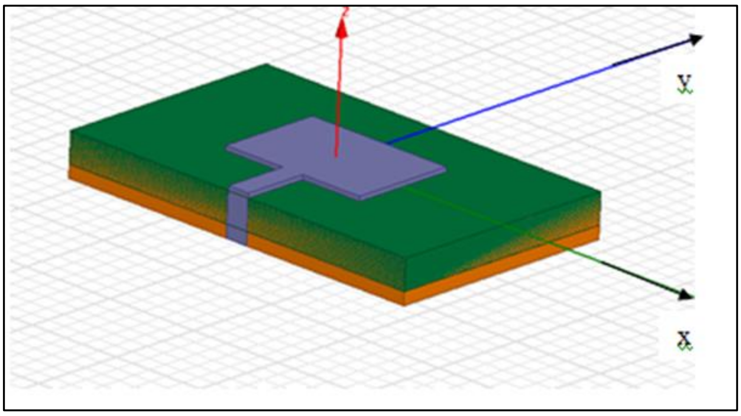

Figure 3 Top view of graphene based rectangular patch antenna

The analysis was performed using a graphene patch on a silicon dioxide substrate material with a thickness of 10µm and dielectric permittivity of εr = 4.0. The wave propagation velocity of graphene depends on the patch dimensions, its resonant frequency, and the Fermi energy of the structure. Based on this concept, the resonant frequency of a graphene-based antenna can be evaluated using Equation (1).

$$f_o = \frac{1}{2\pi\sqrt{LC}} \qquad (1)$$

Based on the ability of graphene to support plasmonic resonant frequencies in the THz regime (0.1 - 10THz), we consider the frequency range from 1THz to 10 THz, with a fundamental frequency of 5.5 THz.

Table 1 Design Parameters for Nano Patch Antenna**.**

Design measurement	**parameters**
Length of the Patch	22µm
Width of the Patch	30µm
Height of Substrate (H)	10µm
Length of Substrate	100µm
Width of Substrate	63µm
Length of feed line	21µm
Width of feed line	6.0µm

5. Results and Discussions

Table . 2 shows a summary of the results extracted for varying the width of the graphene patch over silicon dioxide as a substrate with a height (H) of 10 µm adopted as the preferred height. The patch varies from 30µm, 32 µm, 34 µm, 38 µm and 42 µm. The results showed that varying the width of the patch did not affect the resonating frequency. The maximum return loss of -24.5482, -24.4774 and -24.4001is achieved for the patch width of 32 µm, 34 µm and 38 µm respectively, with a perfect VSWR of 1.0302, 1.0387, and 1.0480. This result shows an improvement in the VSWR of 1.1, 1.2, 1.4, and 1.7 obtained by Rajni and Anupma (2016), performed over different substrate materials. A remarkable bandwidth improvement of over 500 GHz was also achieved for patch widths of 32 µm, 34 µm, and 38 µm. This further demonstrates that the gain and directivity of the graphene nano-patch antenna are related to patch width. A gain and directivity of above 7 dB were achieved for both patch widths.

Table 2 Simulated Results of Graphene Nano Patch Antenna for Different Patch Width

Patch-Width (μm)	**30(μm)**	**32(μm)**	**34(μm)**	**38(μm)**	**42(μm)**
Parameter					
Resonating frequency (THz)	6.0000	7.0000	7.0000	7.0000	7.0000
Return loss (dB)	-23.3829	-24.5482	-24.4774	-24.4001	-19.8080
VSWR	1.1786	1.0302	1.0387	1.0480	1.7822
Gain (dB)	7.0507	7.1943	7.1841	7.0937	7.1151
Directivity (dB)	7.0816	7.2067	7.1938	7.0961	7.1205
Lower frequency at(-10dB)	5.8031	6.6862	6.6896	6.6800	6.7855
Upper frequency at (-10dB)	6.2066	7.2089	7.2087	7.2080	7.1972
Bandwidth(GHz)	403.5	522.7	519.1	528.0	411.7

6. Conclusion

In conclusion, this study elucidates the influence of graphene patch width variations on the performance and bandwidth of nano-patch antennas. Simulations conducted using the High-Frequency Structural Simulator (HFSS) revealed that while the resonating frequency remained invariant across different patch widths, the performance metrics varied significantly. Specifically, patch widths of 32 μm, 34 μm, and 38 μm yielded the highest return losses of -24.5482, -24.4774, and -24.4001, respectively, and demonstrated good VSWR values of 1.0302, 1.0387, and 1.0480. These widths also facilitated a substantial bandwidth enhancement exceeding 500 GHz. Additionally, the 32 μm and 34 μm patches exhibited notable gain and directivity, surpassing 7 dB. These findings highlight the critical role of patch width in optimizing the gain, directivity, and overall efficiency of graphene nano-patch antennas, offering essential insights for advanced antenna design in nanotechnology applications.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Da Costa MR, Kibis O, Portnoi M. Carbon nano-tubes as a basis for terahertz emitters and detectors. Microelectronics J. 2009;40(45):778-778.

[2] Llatser I, Chigrin C, Cabellos-Aparicio A, Jornet MJ, Alarcon E, Chigrin DN. Graphene based nano-patch antenna for terahertz radiation. Photonics Nanostruct Fundam Appl. 2021;10(4):353-358.

[3] Zhou T, Cheng Z. Miniaturized tunable terahertz antenna based on graphene. Microw Opt Technol Lett. 2014;56(8):1792-1794.

[4] Llatser I, Mestres S, Abadal S, Alarcon E. Time and frequency domain analysis of molecular absorption in short-range terahertz communications. IEEE Antennas Wireless Propag Lett. 2015;14:350-353.

[5] Ozbay E, Tamelkuran B, Bayindir M. Microwave applications of photonic crystals. Prog Electromagn Res PIER. 2003;41:185-209. doi:10.2528/pier0201808.

[6] Gonzalo R, De Maagt P, Sorolla M. Enhanced patch-antenna performance by suppressing surface waves using photonic band gap substrates. IEEE Trans Microw Theory Tech. 1999;47(11):213-218. doi:10.1109/22.798009.

[7] Meade RD, Rappe AM, Brommer KD, Joannopoulos JD. Nature of the photonic band gap: some insights from a field analysis. J Opt Soc Am B. 1993;10:328-332. doi:10.1364/JOSAB.10.000328.

[8] Geim AM, Novoselov KS. The rise of graphene. Nat Mater. 2007;6:183-191. doi:10.1038/nmat1849.

[9] Novoselov KS, Geim AK, Morozov SV, Jiang D, Zhang Y, Dubonos SV. Electric field effect in atomically thin carbon films. Science. 2004;306:666-669. doi:10.1126/science.1102896.

[10] Song R, Wang Q, Mao B, Wang Z, Tang D, Zhang B. Flexible graphite films with high conductivity for radio frequency antennas. Carbon. 2018;130:164-169. doi:10.1016/J.carbon.2018.01.019.

[11] Warner JH, Schaffel F, Rummeli M, Bachmatiuk A. Graphene fundamentals and emergent applications. Oxford, UK: Elsevier; 2013.

[12] Bozzi M, Pierantoni L, Bellucci S. Applications of graphene at microwave frequencies. Radioengineering. 2015;24:661-669. doi:10.13164/re.2015.0661.

[13] Gusynin VP, Sharapov SG, Carbotte JP. Magneto-optical conductivity in graphene. J Phys Condens Matter. 2007;19:026222. doi:10.1088/0953-8984/19/2/026222.

[14] Mohamed KA, Hosni A, Ali G. Terahertz graphene-based reconfigurable patch antenna. Prog Electromagn Res Lett. 2017;71:69–76.

[15] Kavitha S, Sairam KVSSSS, Ashish S. Substrate effects on the plasmonic resonance of graphene nano-antenna. Appl Math Model Comput Simul. 2022. doi:10.3233/ATDE221098.

[16] Llatser I, Kremers C, Chigrin DN, Jornet JM, Lemme MC, Cabellos-Aparicio A, et al. Characterization of graphene-based nano-antennas in the terahertz band. Eur Conf Antennas Propag (EuCAP). 2012:194-198.

[17] Llatser I, Kremers C, Chigrin DN, Jornet JM, Lemme MC, Cabellos-Aparicio A, et al. Graphene-based nano-patch antennas for terahertz radiation. Photonics Nanostruct Fundam Appl. 2012;10:353-358.

[18] Kavitha S, Sairam KVSSSS, Ashish S. Graphene plasmonic nanoantenna for terahertz communication. 2012. doi:10.1007/s42452-022-04986-1.

[19] Qasem N, Marhoon HM. Simulation and optimization of a tunable rectangular microstrip patch antenna based on hybrid metal-graphene and FSS superstrate for fifth-generation applications. TELKOMNIKA Telecommun Comput Electron Control. 2020;18(4):1719-1730.

[20] Abdulnabi HA, Al-Aboosi YY. Design of tunable multiband hybrid graphene metal antenna in microwave regime. Indones J Electr Eng Comput Sci. 2018;12(3):1003-1009.

[21] Nanda BS, Puttaswamy PS. Modeling and simulation of graphene field-effect transistor (GFET). Int J Electr Comput Eng. 2019;9(6):4826–4835.