Analysis and Design of Microstrip Patch Antenna on Photonic Band Gap (PBG) Substrate at Terahertz Regime

S. M. Shamim (Shamim@mbstu.ac.bd)
Mawlana Bhashani Science and Technology University
Nahid Arafin
Bangladesh Army University of Engineering & Technology
Umme Salma Dina
Bangladesh Army University of Engineering & Technology
Sumaiya Shemu
Bangladesh Army University of Engineering & Technology
Rezaul Karim
Mawlana Bhashani Science and Technology University

Research Article

Keywords: Microstrip, Patch Antenna, Terahertz, Wireless Communication, Photonic Band Gap

Posted Date: May 31st, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1643577/v1

Abstract

For future wireless communication, low-cost, low profile, minimal weight and high performance antenna is required to support high-speed data transmission. This paper presents a graphene based wideband microstrip patch antenna at 1.10THz resonate frequency. Graphene has been used in the proposed antenna for higher electrical conductivity, mobility, and saturation severity in THz band regime. The proposed antenna is mounted on silicon substrate that employed Photonic Band Gap (PBG) having a dielectric constant of 11.9. The outcome of this work has been described in terms of return loss (S11), gain, directivity, voltage standing wave ratio (VSWR) and radiation pattern for both E-plane and H-plane. The proposed antenna has minimal return loss – 48.95dB, gain 3.96dB, VSWR 1.054 and impedance bandwidth 26% which may be an excellent candidate for wireless communication as well as explosive detection, material characterization, medical imaging, homeland defense system etc. All the design and simulations of the proposed antenna has been performed by using commercially available electromagnetic software CST Microwave Studio.

I. Introduction

In 21st century graphene has termed as one of the significant material in wireless communication due to amazing electrical and optical properties [1]. According to Edholm's law, wireless data rates tend to be doubled in eighteen months [2]. Higher channel capacity is required for the next generation communication system which demands the exploitation of higher frequency band for data transfer [3]. To meet high-speed data transmission, one of the possible solutions is terahertz (THz) frequency band which reduce the spectrum scarcity of current wireless communication system. The terahertz frequency band lies between the 0.1THz to 10THz. Although the frequency band below and above these band have extensively investigated but THz band is one of the least explored frequency band for future wireless communication [4]. The higher bandwidth capacity and less attenuation is possible in THz frequency band [5]. This frequency band has also different applications in medical imaging [6], defense and security based technology [7] and ultra-first spectroscopy of materials [8] etc. Internet of Thing (IoT) based devices may also be benefitted from THz spectrum [9].

In addition, high performance antenna is required to support THz band wireless communication. Microstrip patch antenna one of the possible solution to support THz communication. It has low cost, low profile, planner configuration, easy to fabricate and feeding, superior probability and easy to integrate with antenna elements like Monolithic Microwave Integrated Circuits (MMIC's) [10–11]. Microstrip patch antenna has variety of application are mobile communication, personal wireless communications, radar, radio frequency identification (RFID), surveillance systems, aerospace telecommunications, weapons and missile, Global Positioning System (GPS) and many others [12–13]. The radiating patch is an important part of microstrip patch antenna. The uses of graphene as a radiating patch rather than copper materials is increasing day by day. Graphene is an allotrope of carbon packed into a two-dimensional (2D) honeycomb and hexagonal lattice structure. It is widely being used in Nano-photonics, Nano-electronics and THz wireless communication for outstanding chemical, mechanical and optical properties [14–16].

At room temperature, graphene carrier mobility is very high and may vary from 8000-200000 $cm^2 V^{-1} s^{-1}$. The carrier interband transition and carrier intraband transition are the two parts of graphene conductivity.

Different researcher has been studying on antenna that works in terahertz frequency for wireless communication for various application. Singh *et al.*, [17] has been presented trapezoidal microstrip patch antenna for THz wireless application with Photonic Band Gap (PBG) based substrate. They have shown that PBG substrate improves the performance of the antenna, like return loss, gain and bandwidth. Graphene based patch antenna on polyimide substrate in the frequency range 0.725–0.775THz has been analyzed and investigated by Anand *et al.*, [18]. Singhal *et al.*, has been reported [19] hexagonal slotted antenna with microstrip feedline in terms of VSWR, input impedance, realized gain and radiation properties for 0THz-12THz frequency using polyimide substrate. Graphene based dipole antenna with tunable resonant frequency has been presented by Tripathi *et al.*, [20]. An elliptical microstrip patch antenna with polyimide substrate for THz wireless application reported by Singhal *et al.*, [21]. Their proposed antenna result has been described in terms of directivity, peak realized gain, radiation efficiency and VSWR. Rectangular microstrip patch antenna at 1THz resonant frequency has been proposed by Nickpay *et al.*, [22] for wireless communication.

In this paper, a graphene based microstrip patch antenna with using Silicon substrate has been proposed for THz applications. The main novelty of the proposed antenna has achieved reduction in size and larger impedance bandwidth. The photonic band gap (PBG) structure has been used in the propose antenna in order to enhance the antenna performance. The objective of the proposed antenna design is to improve the important antenna characteristics in terms of return loss, gain, VSWR and bandwidth. The simulated result of this paper shows that, propose antenna has minimal return loss – 48.95dB, gain 3.97dB, VSWR 1.054 and impedance bandwidth 26% which would be an excellent candidate for medical imaging, bio-sensing, explosive detection, chemical detection etc.

The rest of the paper is organized as follows. Section II presents design and configuration of the antenna. All the simulation results and discussion with previous studies has been reported in section III. Finally, section IV concludes the works.

Ii. Antenna Design And Configuration

The geometry of the proposed microstrip patch antenna at 1.10THz resonant frequency has been shown in Figure-1. The antenna comprises with three plane are ground plane, substrate plane and radiating patch plane. The copper material has been used as a ground plane with the dimension of 100x100 μm^2. The antenna has been simulated using silicon substrate with relative permittivity 11.9, the thickness of 30μm and loss tangent 0.00025. PBG structures exhibit wide band pass and band rejection properties at microwave and THz frequencies. This material is formed by introducing periodic perturbation such as dielectric rods, holes and patterns m waveguides and PCB substrates. The PBG structure is etched on the substrate by drilling periodic circular cylinder. It has many applications especially in microwave circuit, optical communication, antenna and so forth [24–27]. The physical mechanism of the photonic band gap suppresses the surface waves propagating along the surface of the substrate. The PBG structure in the antenna reflects most of the radiating electromagnetic energy to the substrate significantly [28–29]. The different modes of electromagnetic wave propagation have different field distributions and dispersions properties within photonic band gap based materials which differ significantly from those in free space.

The graphene material has been used as a radiating patch for their amazing electrical, mechanical, thermal and optical characteristics in terahertz regime. The graphene based radiating patch is etched in the top surface of silicon substrate. The value of length and width of the radiating patch is of 50µmX50µm. Different feeding techniques are used to excite the microstrip patch antenna. Microstrip line, aperture coupling and coaxial coupling are the common feeding techniques used to feed the antenna. Microstrip line feeding techniques has been used in the proposed antenna. Because, it has simple fabrication procedure and good impedance matching with input signal. All the antenna dimension for the proposed antenna at 1.10THz centre frequency have been tabulated on table-1. The optimized dimensions of the proposed microstrip patch antenna are obtained by using the EM software CST microwave studio.

Table-1 Geometric parameters of the graphene-based antenna for center frequency of 1.10THz.

Parameter	Dimensions (µm)
Length of the patch (Lp)	50
Width of the patch (Wp)	50
Length of the substrate (Ls)	100
Width of the substrate(Ws)	100
Length of the Ground (Lg)	100
Width of the ground (Wg)	100
Height of the substrate (Hs)	30
Microstrip feed width (Wf)	8

Iii. Result And Analysis

In wireless communication, Terahertz (THz) band spectrum plays important role in ultra-wide band and high speed secured data transmission. In this research, a high performance antenna has been designed and analyzed for THz application using CST microwave studio. The performance of the proposed microstrip patch antenna has been scrutinized in terms of return loss (s11), antenna gain, directivity, VSWR, radiation efficiency and radiation pattern for both E-plane and H-Plane. The return loss plot illustrates that the proposed microstrip patch antenna is resonant at a frequency of 1.10THz with corresponding return loss (S11) -48.95dB as shown in Figure-2. The impedance bandwidth of the designed antenna is 280GHz ranging from 0.99THz to 1.27THz. Due to Photonic Band Gap (PBG) structure, the electromagnetic wave energy is radiated in the substrate significantly [30] and minimal return loss – 48.95 dB has achieved at centre frequency 1.10THz.

Voltage Standing Wave Ratio (VSWR) is a function of reflection coefficient which measure the mismatch between the transmission line and antenna. The VSWR characteristics of the proposed antenna is depicted in Figure-3 using blue squared solid line.

The impedance between transmission line and antenna must be well matched for delivering maximum power to antenna [17]. In ideal, minimum value of VSWR is 1 which indicates entire power is accepted and there will be no reflection from the antenna. Photonic Band Gap (PBG) structure has also effect to achieve minimum VSWR [31]. The proposed antenna has VSWR of 1.05 at 1.10THz resonate frequency which is near to ideal cases. The value of VSWR is less than 2 are tolerable for the antenna in practical application.

In addition, gain and directivity are the important parameters that must be taken into account for antenna performance analysis. The directivity is an ability of an antenna to focus the energy in one or more particular directions. The gain of an antenna is the measures of degree of directivity in the antenna's radiation pattern. Figure-4 shows gain and directivity are about 3.96dB and 7.28dB respectively for the proposed antenna which is basically encouraging result at 1.10 THz resonant frequency for wireless communication. Due to substrate and ground plane losses, gain and directivity are increasing and decreasing form which are said by Singhal *et al.* [21]. The high gain and directivity based antenna are preferentially radiate in a particular direction.

The E-plane and H-plane far field radiation pattern of the proposed antenna has been depicted in Figure-5. The value of main lobe magnitude, main lobe direction, 3dB angular width and side lobe level for the E-plane are about 2.25dBi, 0.0 degree, 127.0 degrees and – 3.8dB respectively. Consequently, main lobe magnitude, main lobe direction, 3dB angular width and side lobe level are about 6.33dBi, 51 degrees, 67.3 degree and – 4.0dB respectively for the H-plane.

The 3D far field radiation pattern has been shown in Figure-6 for the proposed antenna. It is observed that the proposed antenna has good radiation patterns for both H-plane and E-plane at resonate frequency 1.10THz. A comparison study of the proposed antenna has been tabulated in table-2 with the other design in the literature. The table-2 depicts the distinctive differences in terms of antenna size, resonant frequency, return loss, directivity, impedance bandwidth and substrate type.

Table-2 Comparative Analysis of the Proposed Antenna with Previous Studies

Reference	Size (μm^2)	Frequency (THz)	Return Loss(dB)	Directivity (dB)	Impedance Bandwidth (%)	Substrate Type
[20]	120x60	3.5	− 39.7	9.31	15.6	Quartz
[18]	208.98 × 433.2	0.75	− 36	5.71	-	Polyimide
[32]	-	0.69	− 27	6.57	-	Quartz
[33]	208.90x422	0.67	-81.18	5.08	5.85	Polyimide
[34]	800x600	0.63	-44.71	8.612	5.75	Polyimide
Proposed Work	100x100	1.10	-48.95	7.28	26.25	Silicon

The analysis has been performed mainly in terms of antenna size and extended impedance bandwidth. Since each of the reported antenna have unique in design, their − 10dB return loss and impedance bandwidth are also different. The comparison table shows that propose antenna has highest 26.25% impedance bandwidth. The size of the proposed antenna is also smaller compare to others. Even though Tripathi *et al.* [20] has proposed small antenna in size but their impedance bandwidth is narrow compare to our proposed antenna. The overall performance comparison of the antenna with other designs shows that our proposed design has better radiation characteristics than the previously reported designs. The proposed antenna is promising for future wireless application especially in explosive detection, chemical detection, medical imaging and airport security analysis etc.

Iv. Conclusion

A graphene based microstrip patch antenna on a PBG substrate has been demonstrated in this research at 1.10THz frequency. The performance of the proposed patch antenna has reported in terms of different radiation parameter are antenna gain, directivity, return loss and impedance bandwidth by implementing the periodic PBG structures on silicon substrate. The result of this paper shows minimum return loss − 48.95dB, maximum directivity 7.28dB and optimized VSWR 1.054, which is near to ideal cases. Furthermore, the achieved fractional impedance bandwidth of the designed antenna is 26.25%. Since microstrip patch antenna is very popular for wireless communication, the proposed antenna would be an excellent candidate for future wireless technology i.e medical imaging, defense and security based technology, ultra-first spectroscopy of materials etc.

Declarations

Funding Information: No funding was received

Conflict of Interest: The authors declare that they have no conflict of interest.

Data Availability: The datasets analyzed during the simulation are available from the corresponding author on reasonable request.

Author Contribution: All authors contributed to the study, conception, design, and simulations. Data collection, analysis, and simulation were initially carried out by S. M. Shamim, Nahid Arafin, and Umme Salma Dina. Additional input to analysis and simulation was given by Sumaiya Shemu and Rezaul Karim. All authors contributed to complete the writing and presentation of the whole manuscript.

References

1. Khan, M. A. K., Shaem, T. A., & Alim, M. A. (2020). Graphene Patch Antennas with Different Substrate Shapes and Materials. Optik, *202*, 163700.
2. Cherry, S. (2004). Edholm's Law of Bandwidth. IEEE spectrum, *41*(7), 58–60.
3. Koenig, S., Lopez-Diaz, D., Antes, J., Boes, F., Henneberger, R., Leuther, A., … Zwick, T. (2013). Wireless Sub-Thz Communication System with High Data Rate. Nature photonics, *7*(12), 977.
4. Bansal, G., Marwaha, A., & Singh, A. (2020). A Graphene-Based Multiband Antipodal Vivaldi Nanoantenna for UWB Applications. Journal of Computational Electronics, 1–10.
5. Akyildiz, I. F., Jornet, J. M., & Han, C. (2014). Terahertz Band: Next Frontier for Wireless Communications. Physical Communication, *12*, 16–32.
6. Ji, Y. B., Oh, S. J., Kang, S. G., Heo, J., Kim, S. H., Choi, Y., … Haam, S. J. (2016). Terahertz Reflectometry Imaging For Low and High Grade Gliomas. Scientific reports, *6*(1), 1–9.
7. Corsi, C., & Sizov, F. (Eds.). (2014). *Thz and Security Applications: Detectors, Sources and Associated Electronics for Thz Applications*. Springer.
8. McIntosh, A. I., Yang, B., Goldup, S. M., Watkinson, M., & Donnan, R. S. (2012). Terahertz Spectroscopy: A Powerful New Tool for The Chemical Sciences?. Chemical Society Reviews, *41*(6), 2072–2082.
9. Nagatsuma, T., Ducournau, G., & Renaud, C. C. (2016). Advances in Terahertz Communications Accelerated by Photonics. Nature Photonics, *10*(6), 371.
10. Prabu, R. T., Benisha, M., Bai, V. T., & Ranjeetha, R. (2019). Design of 5G mm-Wave Antenna Using Line Feed and Corporate Feed Techniques. In *Smart Intelligent Computing and Applications* (pp. 367–380). Springer, Singapore.
11. Kumar, P., Thakur, N., & Sanghi, A. (2013). Micro Strip Patch Antenna for 2.4 GHZ Wireless Applications. International Journal of Engineering Trends and Technology (IJETT), *4*(8).
12. Khraisat, Y. S. (2012). Design of 4 Elements Rectangular Microstrip Patch Antenna with High Gain for 2.4 Ghz Applications. Modern applied science, *6*(1), 68.
13. Prabu, R. T., Benisha, M., Bai, V. T., & Ranjeetha, R. (2019). Design of 5G mm-Wave Antenna Using Line Feed and Corporate Feed Techniques. In *Smart Intelligent Computing and Applications* (pp. 367–380). Springer, Singapore.

14. Wang, C., Yao, Y., Yu, J., & Chen, X. (2019). 3d Beam Reconfigurable THz Antenna with Graphene-Based High-Impedance Surface. Electronics, *8*(11), 1291.
15. Dhasarathan, V., Bilakhiya, N., Parmar, J., Ladumor, M., & Patel, S. K. (2020). Numerical Investigation of Graphene-Based Metamaterial Microstrip Radiating Structure. Materials Research Express, *7*(1), 016203.
16. Hanson, G. W. (2008). Dyadic Green's Functions for an Anisotropic, Non-Local Model of Biased Graphene. IEEE Transactions on antennas and propagation, *56*(3), 747–757.
17. Singh, A., & Singh, S. (2015). A Trapezoidal Microstrip Patch Antenna on Photonic Crystal Substrate for High Speed Thz Applications. Photonics and Nanostructures-Fundamentals and applications, *14*, 52–62.
18. Anand, S., Kumar, D. S., Wu, R. J., & Chavali, M. (2014). Graphene Nanoribbon Based Terahertz Antenna on Polyimide Substrate. Optik, *125*(19), 5546–5549.
19. Singhal, S., & Budania, J. (2019). Hexagonal Fractal Antenna for Super Wideband Terahertz Applications. Optik, 163615.
20. Tripathi, S. K., Kumar, M., & Kumar, A. (2019). Graphene Based Tunable and Wideband Terahertz Antenna for Wireless Network Communication. Wireless Networks, *25*(7), 4371–4381.
21. Singhal, S. (2019). Ultrawideband Elliptical Microstrip Antenna for Terahertz Applications. Microwave and Optical Technology Letters, *61*(10), 2366–2373.
22. Nickpay, M. R., Danaie, M., & Shahzadi, A. (2019). Wideband Rectangular Double-Ring Nanoribbon Graphene-Based Antenna for Terahertz Communications. IETE Journal of Research, 1–10.
23. Parveen, K., Sabir, M., Kumari, M., & Goar, V. (2019). A Slotted Microstrip Patch Antenna for 5G Mobile Phone Applications. In *Smart Innovations in Communication and Computational Sciences* (pp. 173–178). Springer, Singapore.
24. Horii, Y., & Tsutsumi, M. (1999). Harmonic Control by Photonic Bandgap on Microstrip Patch Antenna. IEEE Microwave and Guided Wave Letters, *9*(1), 13–15.
25. Colburn, J. S., & Rahmat-Samii, Y. (1999). Patch Antennas on Externally Perforated High Dielectric Constant Substrates. IEEE Transactions on Antennas and Propagation, *47*(12), 1785–1794.
26. Ting-Gen, S., Yue-Qun, Z., Zheng-Hua, L., Pei-Lai, J., Jin, S., & Feng-Chao, Y. (2009). Influence of A Novel Periodic Structure on Patch Antenna. Applied Physics A, *96*(3), 789–792.
27. Zhou, Y. Q., Yu, F. C., Shen, T. G., Ji, P. L., Ge, J., Gen, J. F., & Len, J. (2008). Investigation of Patch Antennas Based on Embedded Multiple PBG Structure. IEEE Photonics Technology Letters, *20*(20), 1685–1687.
28. Sharma, A., Dwivedi, V. K., & Singh, G. (2008, July). THz Rectangular Patch Microstrip Antenna Design Using Photonic Crystal As Substrate. In *Progress in Electromagnetic Research Symposium, Cambridge, USA* (pp. 161–165).
29. Li, Z., Xue, Y. L., & Shen, T. (2012). Investigation of Patch Antenna Based on Photonic Band-Gap Substrate with Heterostructures. *Mathematical Problems in Engineering*, *2012*.

30. Azizi, S., Nouri-Novin, S., Seyedsharbaty, M. M., & Zarrabi, F. B. (2018). Early Skin Cancer Detection Sensor Based on Photonic Band Gap and Graphene Load at Terahertz Regime. Optical and Quantum Electronics, *50*(6), 230.
31. Kushwaha, R. K., Karuppanan, P., & Malviya, L. D. (2018). Design and Analysis of Novel Microstrip Patch Antenna on Photonic Crystal in Thz. Physica B: Condensed Matter, *545*, 107–112.
32. Tripathi, S. K., & Kumar, A. (2017). High Gain Highly Directive Graphene Based Terahertz Antenna for Wireless Communication. i-Manager's Journal on Communication Engineering and Systems, *6*(4), 16.
33. Dhillon, A. S., Mittal, D., & Sidhu, E. (2017). THz rectangular microstrip patch antenna employing polyimide substrate for video rate imaging and homeland defence applications. Optik, *144*, 634–641.
34. Kushwaha, R. K., Karuppanan, P., & Malviya, L. D. (2018). Design and analysis of novel microstrip patch antenna on photonic crystal in THz. Physica B: Condensed Matter, *545*, 107–112.

Figures

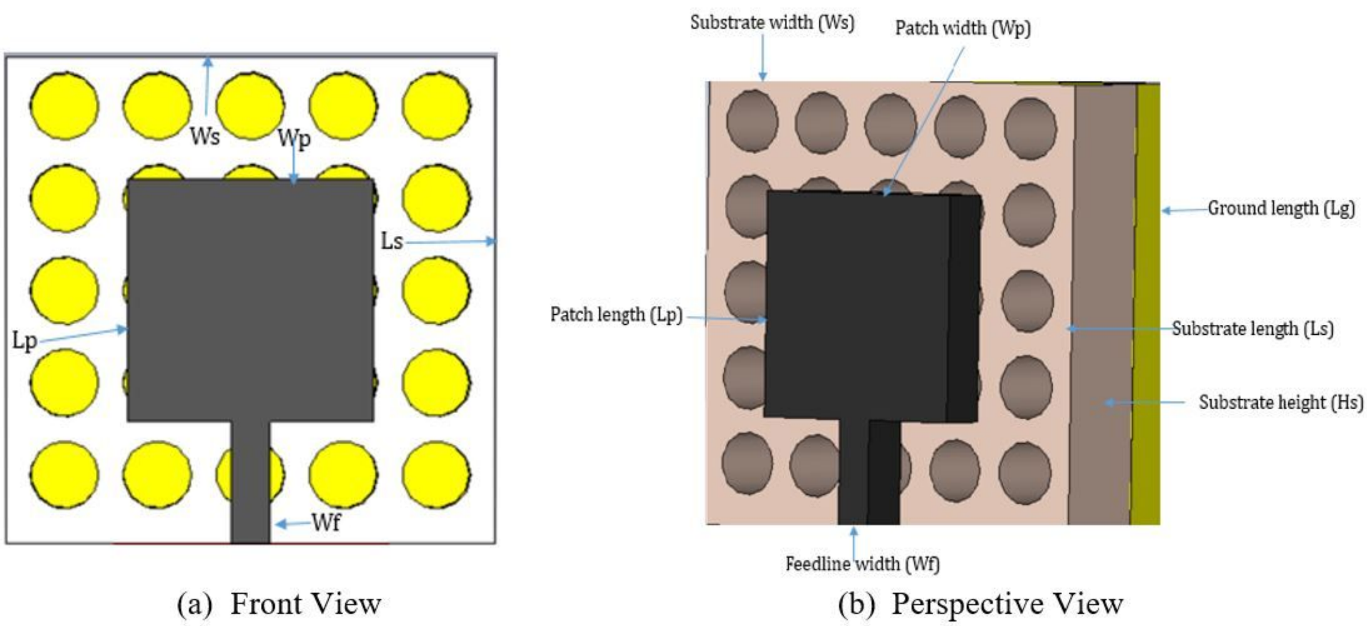

Figure 1

The Schematic Configuration of Proposed Antenna (a) Front view (b) Perspective View

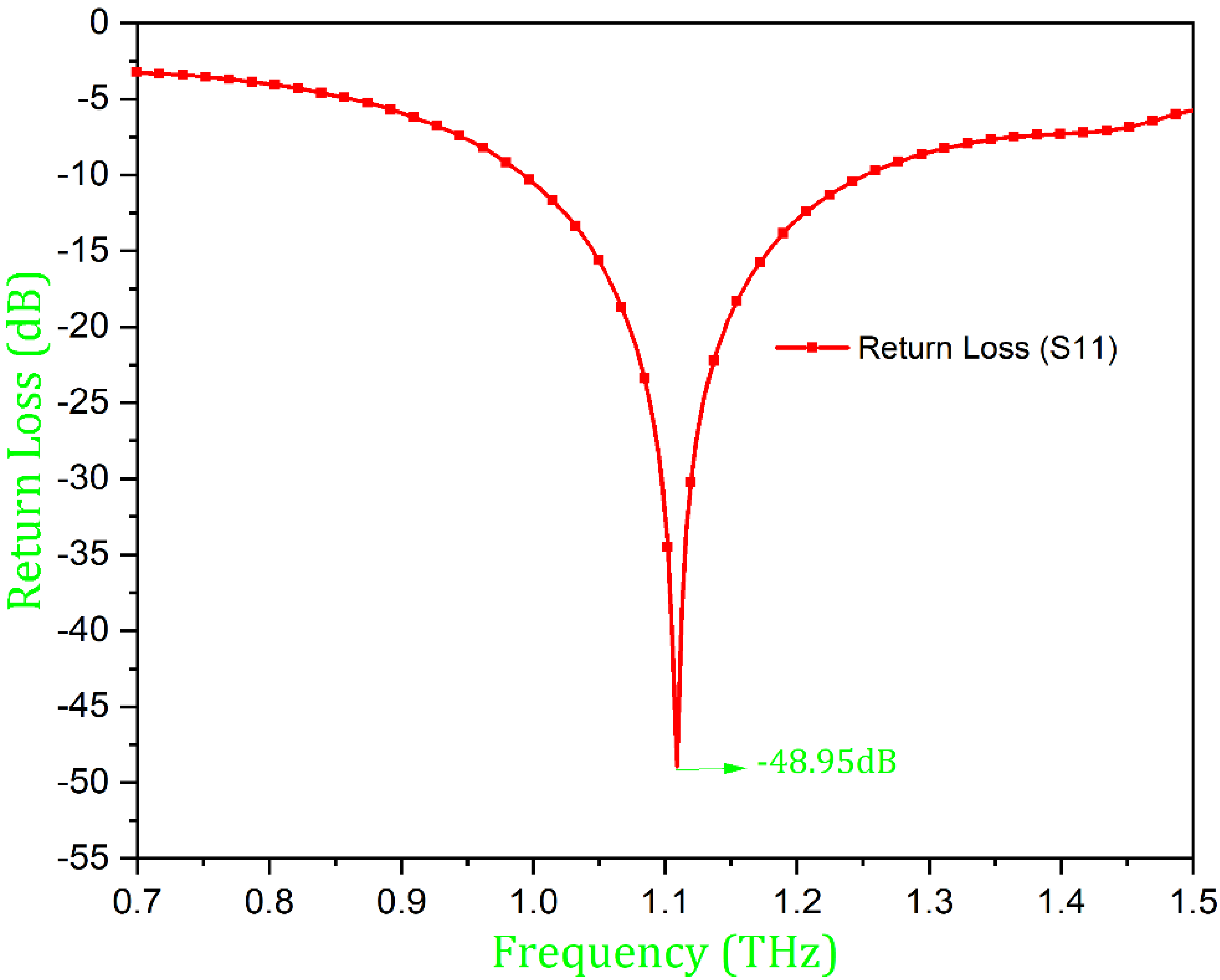

Figure 2

The Return Loss vs Frequency characteristics of the Proposed Antenna

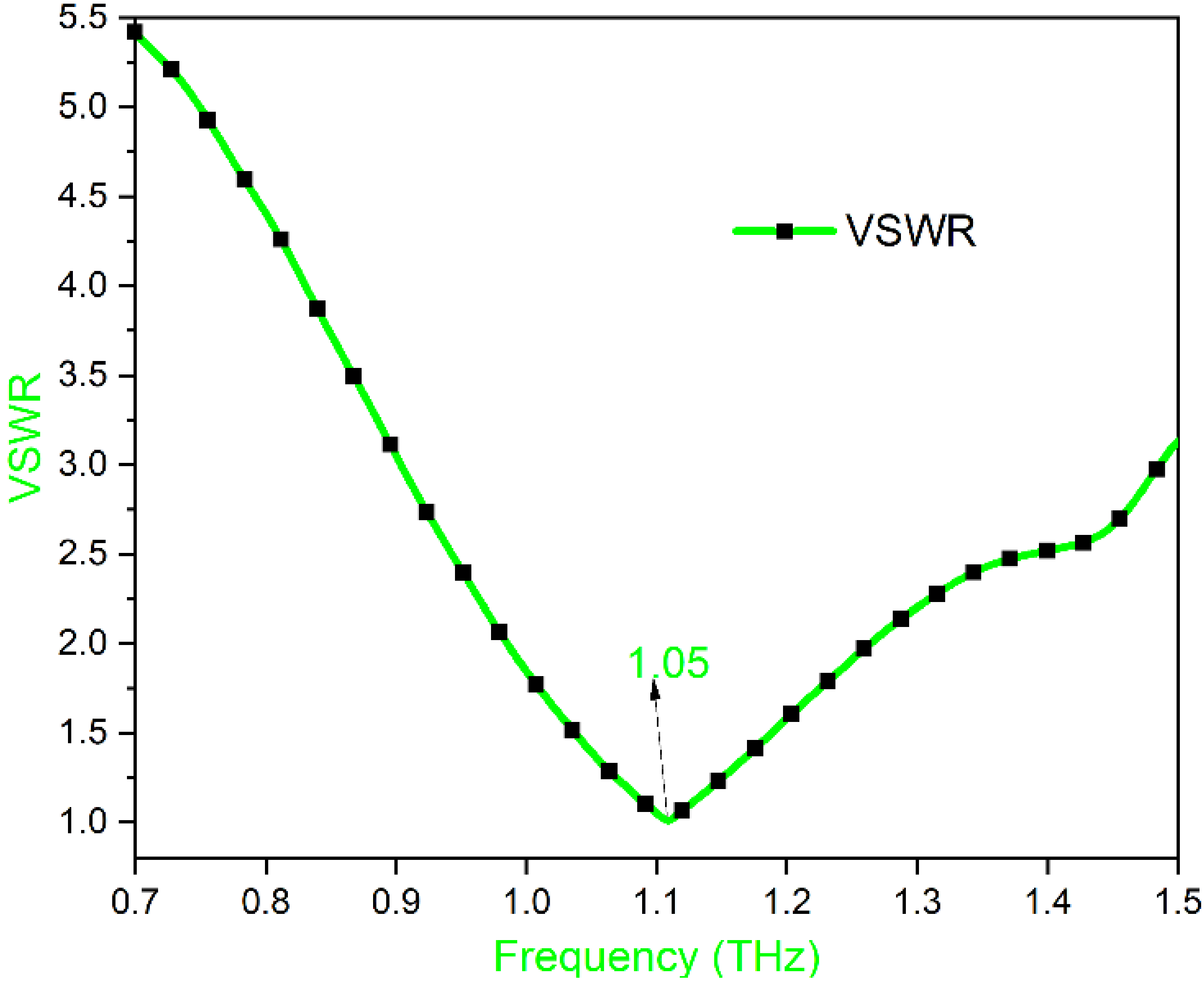

Figure 3

The Voltage Standing Wave Ratio (VSWR) vs Frequency Characteristics of the Proposed Antenna

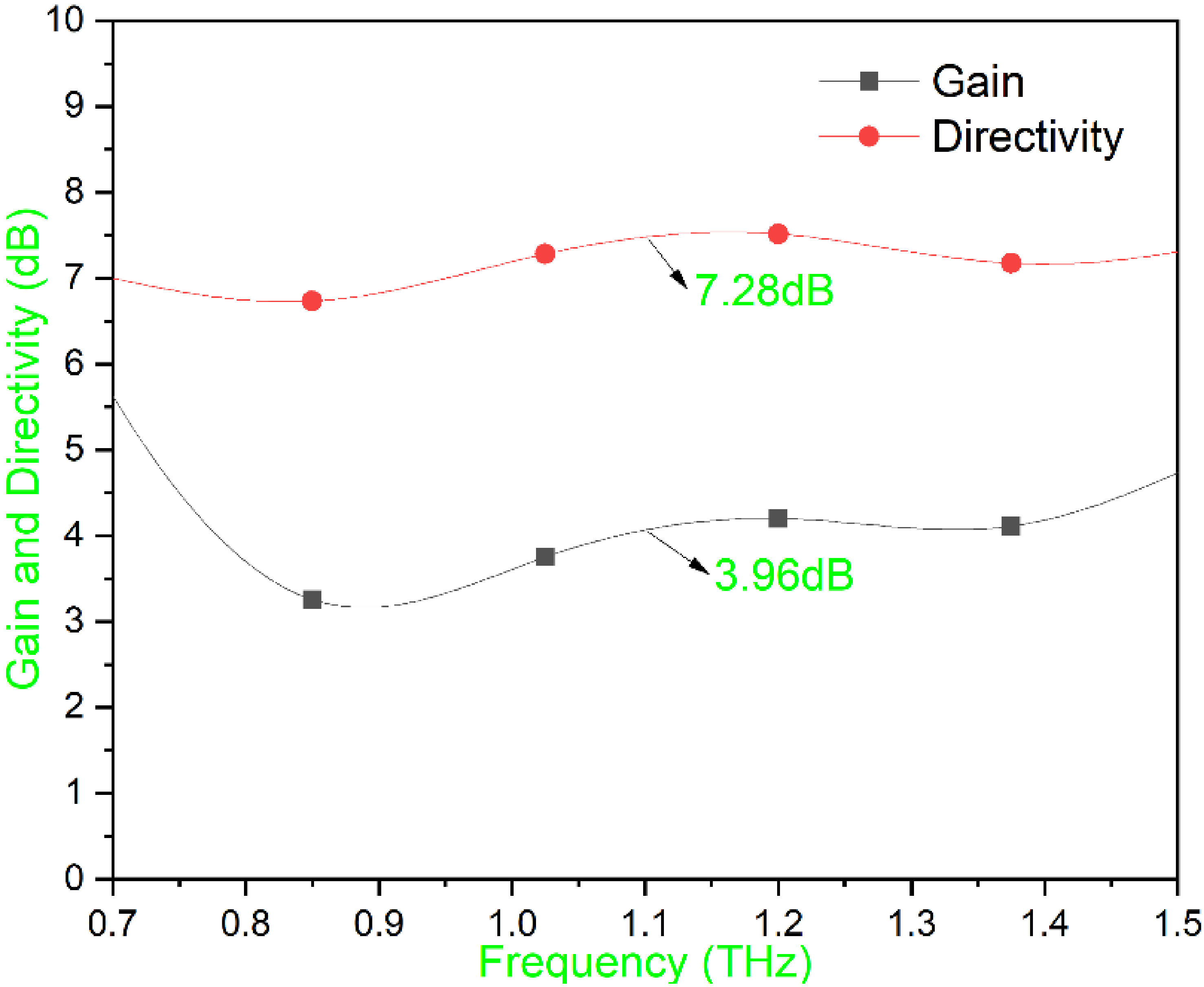

Figure 4

The Gain and Directivity vs Frequency Characteristics of the Proposed Antenna

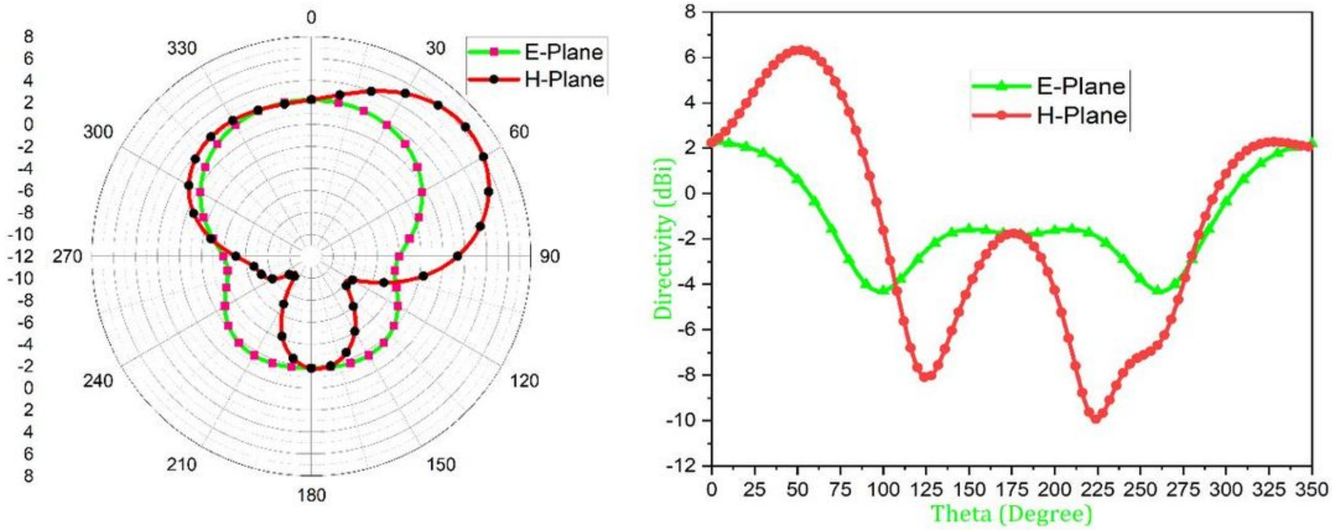

Figure 5

The Radiation Performance of the Proposed Antenna (a) Radiation Pattern and n 3D Form (b) Radiation Pattern in 2D Form.

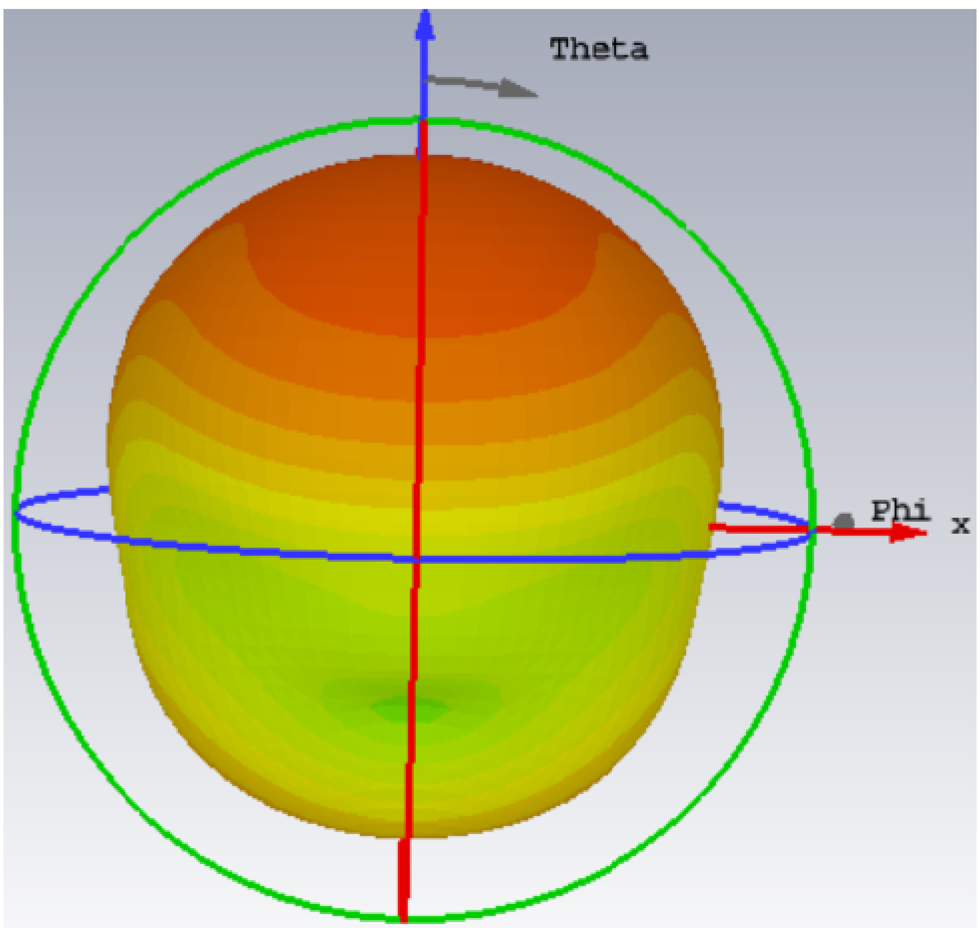

Figure 6

The 3D Radiation Pattern of the Proposed Antenna