Evolution in Electrical and Electronic Engineering Vol. 2 No. 2 (2021) 739-747
© Universiti Tun Hussein Onn Malaysia Publisher's Office

EEEE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/eeee
e-ISSN : 2756-8458

A Feasibility Study for Potential of Graphene and Carbon Nanotubes Patch Antenna in Terahertz

Wan Azrol Iqbal Azahari[1], **Muhammad Ramlee Kamarudin**[1]*, **Siti Nor Hafizah Sa'don**[1],

[1]Faculty of Electrical and Electronic Engineering,
Universiti Tun Hussein Onn Malaysia 86400 Parit Raja, Johor, MALAYSIA

*Corresponding Author Designation

DOI: https://doi.org/10.30880/eeee.2021.02.02.088
Received 06 July 2021; Accepted 22 September 2021; Available online 30 October 2021

Abstract: Today's Eureka moments are in wireless communication technology. There has been a significant increase in the number of new use cases for which 5G is inadequate. 6G will allow a highly intelligent, reliable, scalable, and secure terrestrial wireless network. New antenna structures for wireless communication systems have been designed as a result of increased attenuation for high frequency. The researchers offer a 6G architecture idea as well as antenna specs in the Terahertz wavelength range. According to researchers, such an antenna may be used for a variety of applications, including communications. The major goal of this study is to develop graphene and carbon nanotube (CNT) antennas for a variety of Terahertz bands, as well as to examine the antennas' performance in those bands. The primary objective of the task is to do research and study the proper formula and theory in order to acquire accurate parameters utilising CST Studio, which offers an interface for accessing data. At frequencies ranging from 100 GHz to 500 GHz, a novel design will be developed and tested. It will be based on graphene and carbon nanotube (CNT) materials for comparison of results, and the antenna size will be decreased to minimise meshcells, which will make troubleshooting simpler in a short period of time. Both materials' results suggested that they were suitable for use at terahertz frequencies. This is just one of several steps in the development of graphene and carbon Nanotube antennas. Although the various antennas are not completely developed, they all have potential. There is a market for further research and manufacture of these antennas in the near future.

Keywords: Terahertz Wavelength Band, CST Studio, Graphene, Carbon Nanotube

1. Introduction

Wireless communication systems are the Eureka equivalents of our day, given the rapid technical advancements over the last several decades and symmetrical technologies for the Internet of Things.

Corresponding author: mramlee@uthm.edu.my

The fifth generation (5G) wireless network is the most recent. There are five generations of mobile wireless cellular communications systems in operation today [1]. Since 1980, a new wireless cellular communication generation has emerged approximately every ten years, with the first generation analogue FM cellular systems debuting in 1981, the second generation in 1992, the third generation (3G) in 2001, and the fourth generation (4G) (often referred to as the long-term evolution (LTE)) debuting in 2011 [2].

However, as societal needs evolve, there has been a considerable increase in the number of emergent use cases that 5G cannot adequately service [3]. Holographic teleportation, for example, the next generation of VAR, necessitates Tbps-level data speeds and microsecond-level latency, both of which are challenging to accomplish even with 5G's millimetre wave (mmWave) frequency bands [4]. The primary drivers for a generational leap beyond present wireless networks are a mix of social needs and technology advances that help satisfy those requirements [5]. These factors add up to a compelling case for a focused discussion on the next generation of wireless communications, often known as 6G systems [6].

6G will enable a pervasively intelligent, reliable, scalable, and secure terrestrial wireless network, as well as space communications to construct an ubiquitous wireless network [7]. This article describes our view for the future of wireless communications, including novel use cases and important enabling technologies for 6G [8]. The growth of wireless communication system technologies necessitated the creation of novel antenna structures. The frequency of microstrip planner technology in wireless communication networks is essentially restricted. A conventional antenna can only generate a single fixed directed radiation pattern. Because of the higher attenuation at high frequencies, antennas for high spectrum bands must be designed with care.

The materials used in the antenna have an impact on the frequency it produces. When graphene and carbon nanotubes (CNTs) are compared, the study finds that they emit frequencies at different frequencies. Furthermore, frequency emission fluctuation is mostly caused by the patch size and the feedline from the microstrip patch antenna. The objective of the research is to evaluate two materials used in antenna design, Graphene and Carbon Nanotube (CNT), utilising CST Studio software in terms of frequency emission, radiation pattern, and gain of microstrip patch antennas.

2. Materials and Methods

A new study has been published on antenna design in the Terahertz spectrum bands, which are employed in the Sixth Generation (6G) and it is in line with the project's goal of making an antenna out of various materials. Using CST Studio software, it is required to simulate the design in order to test the materials at a certain frequency.

2.1 Antenna Specification

Table 1 shows the antenna requirements for graphene antenna design. The antenna was a microstrip patch antenna with an operating frequency of 300 GHz. The conducting element was graphene, a lossy metal with a resistance of 0.003 to 0.008 ohm per square. The electrical conductivity was between 1.25 and 3.33 x 10^4 S/m.

The antenna specifications for carbon nanotube antenna design are shown in Table 2. The antenna was a microstrip patch antenna with an operating frequency of 300 GHz. The conducting element was carbon nanotubes, a lossy metal with a resistance of 0.003 to 0.008 ohm per square. The electrical conductivity was between 1.25 and 3.33 x 10^7 S/m.

The antenna designations were Graphene antenna and CNT antenna, respectively, as shown in Figures 1 and Figure 2. Both antennas have different electrical conductivities, with graphene having a value of about 1.25 x 10^4 – 3.33 x 10^4 S/m. In addition, the electrical conductivity of CNT ranges between 1.25 x 10^7 and 3.33 x 10^7 S/m, depending on the CNT material value. Apart than that, both antennas used the same type of substrate which was FR4 (loss free). The parameter value for Graphene antenna and Carbon Nanotubes antenna as shown in Table 3 and Table 4, respectively.

Table 1: Antenna Specification for Graphene

Operating frequency	300 GHz
Antenna design	Microstrip patch antenna
Conductive element	Material : Graphene Type : Lossy metal Resistivity : 0.003 – 0.008 Ω.cm, Thickness : > 100 nm Calculated conductivity : 1.25 x 10^4 – 3.33 x 10^4 S/m
Type of substrate	Material : FR-4 (loss free) Type : Normal Epsilon : 4.3 Thickness : > 100 nm Thermal Conductivity : 0.3 [W/K/m]

Table 2: Antenna Specification for Carbon Nanotubes

Operating frequency	300 GHz
Antenna design	Microstrip patch antenna
Conductive element	Material : Carbon Nanotubes Type : Lossy metal Resistivity : 0.003 – 0.008 Ω.cm, Thickness : > 100 nm Calculated conductivity : 1.25 x 10^7 – 3.33 x 10^7 S/m
Type of substrate	Material : FR-4 (loss free) Type : Normal Epsilon : 4.3 Thickness : > 100 nm Thermal Conductivity : 0.3 [W/K/m]

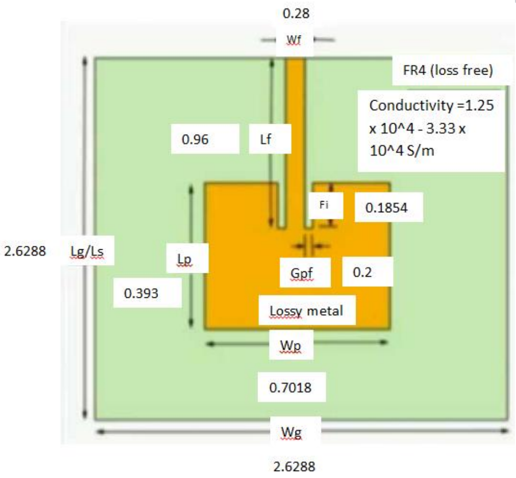


Figure 1: Graphene Antenna

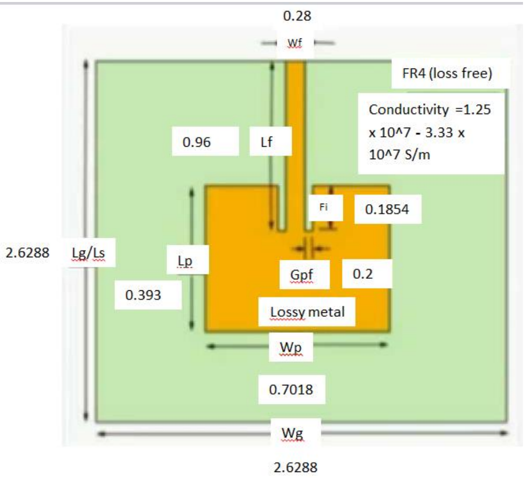


Figure 2: CNT Antenna

Table 3: Parameter for Graphene Antenna

Name	Value
Ws	2.6288
Ls	2.2734
Hs	0.08
Wp	0.7018
Lp	0.393
Hp	0.007
Wf	0.28
Gpf	0.2
Lf	0.96
Fi	0.1854

Table 4: Parameter for Carbon Nanotubes Antenna

Name	Value
Ws	2.6288
Ls	2.2734
Hs	0.08
Wp	0.7018
Lp	0.393
Hp	0.007
Wf	0.28
Gpf	0.2
Lf	0.96
Fi	0.1854

2.2 Methods

To begin, this project flow as shown in Figure 3 must set limits and excitement to ensure that everything is in order while working on the project. Then it requires the most important programme for this project, CST Studio 2020. Create a new project design for the microstrip patch antenna, then design the substrate, choose a patch model, and finally design the bottom and top patches on the antenna. After that, do a setup analysis that assigns the frequencies that have been chosen, which are 100GHz and higher. Assign a vacuum boundary for the antenna's radiation, as well as the outcomes and discoveries.

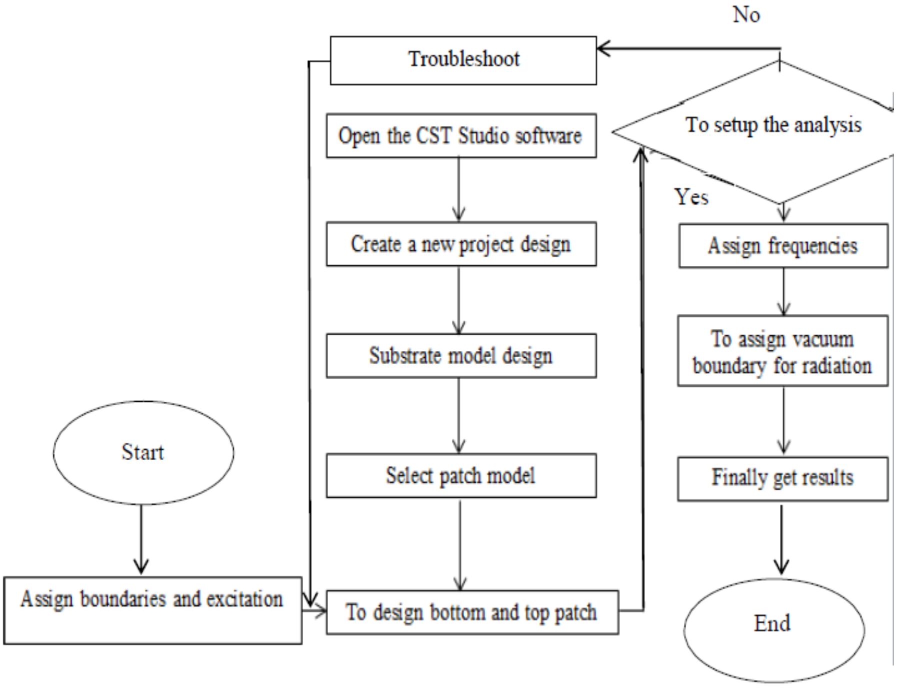


Figure 3: Flowchart of the project

To make a microstrip patch antenna, it must first pick a resonant frequency and a dielectric material. The width of the patch is calculated using Eq.1 [3],[5]-[6].

$$W = \frac{C_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \quad \text{Eq. 1}$$

where, W is the width of the patch, C_0 is the speed of light, ε_r is the dielectric substrate

The effective refractive index value of a patch is an important element in the design of a microstrip patch antenna. It can be calculated using Eq. 2. Some of the radiations that travel from the patch to the ground flow through the air, while others go through the substrate (called fringing). The dielectric constants of air and substrates are not the same.

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}}, \frac{W}{h} > 1 \quad \text{Eq. 2}$$

The antenna's electrical size is enlarged by an amount of (L) due to fringing. As a result, the actual increase in patch length (L) must be computed using Eq. 3 [3],[5- 6]:

$$\frac{\Delta L}{h} = 0.412\frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} + 0.258\right)\left(\frac{W}{h} + 0.8\right)} \quad \text{Eq. 3}$$

where h is the height of the substrate.

The length (L) of the patch is now to be calculated using Eq. 4 [3],[5- 6]:

$$L = 0.412\frac{C_0}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \quad \text{Eq. 4}$$

A patch's dimensions are now known. A substrate's length and width are the same as the ground planes. Equation Eq. 5 and Eq. 6 are used to determine the length of a ground plane (Lg) and the width of a ground plane (Wg) [7]:

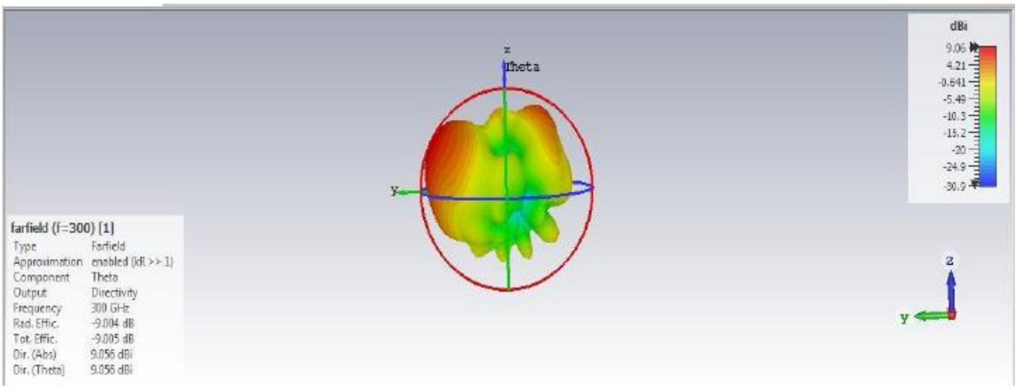
$$L_g = 6h + L \quad \text{Eq. 5}$$

$$W_g = 6h + W \quad \text{Eq. 6}$$

3. Results and Discussion

3.1 Graphene antenna

The gain pattern of the antenna in the farfield is shown in Figure 4. The antenna's highest gain was located above the patch, which is oriented in the direction of theta, while minor lobes were located on the opposite side.



```
farfield (f=300) [1]
Type           Farfield
Approximation  enabled (kR >> 1)
Component      Theta
Output         Directivity
Frequency      300 GHz
Rad. Effic.    -9.004 dB
Tot. Effic.    -9.005 dB
Dir. (Abs)     9.056 dBi
Dir. (Theta)   9.056 dBi
```

Figure 4: Gain of the antenna in the farfield

Figure 5 shows the 2D view gain in the farfield of the antenna. The maximum gain of the antenna was 9.07 dB. The half power (3 dB) beam width was 51.0 degrees.

Figure 5: Farfield Directivity Theta

The antenna's S-parameter is shown in Figure 6. According to the graph below, the antenna radiates best between 180 and 350 GHz. Because S11 was over the -10 dB limit, the antenna will transmit virtually nothing below 180 GHz.

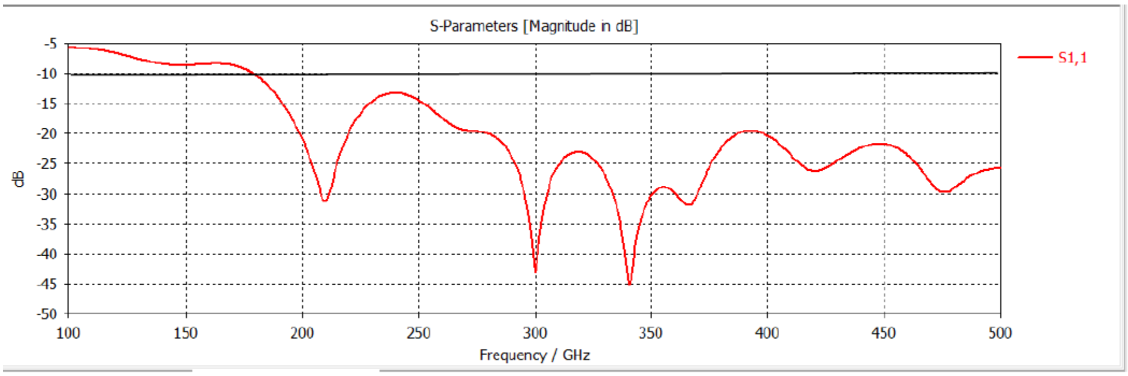


Figure 6: S-parameter of the antenna

The designed antenna's Voltage Standing Wave Ratio (VSWR) vs frequency graph is shown in Figure 7. At 300 GHz, a VSWR of less than 2 was considered appropriate for most antenna applications (equivalent to 1.013).

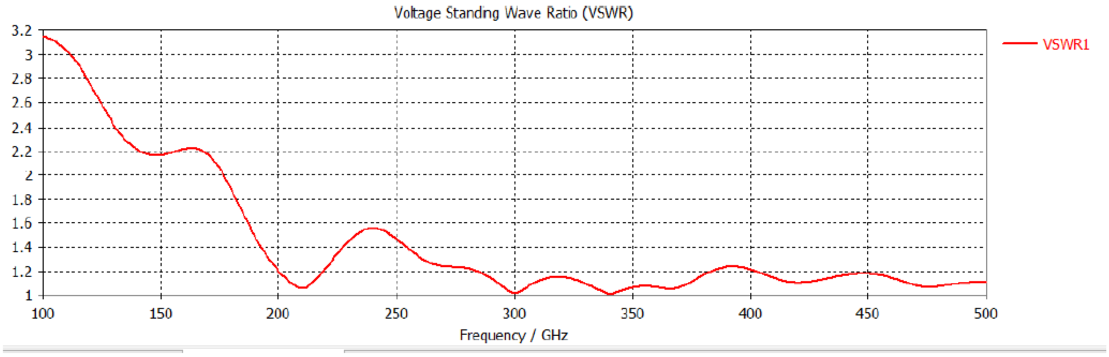


Figure 7: Voltage Standing Ratio (VSWR)

3.2 Carbon Nanotubes Antenna

Figure 8 depicts the antenna's gain pattern in the farfield for Carbon Nanotubes antenna. As with previous graphene, the antenna's highest gain was above the patch, which was in the direction of theta, and minor lobes were on the other side.

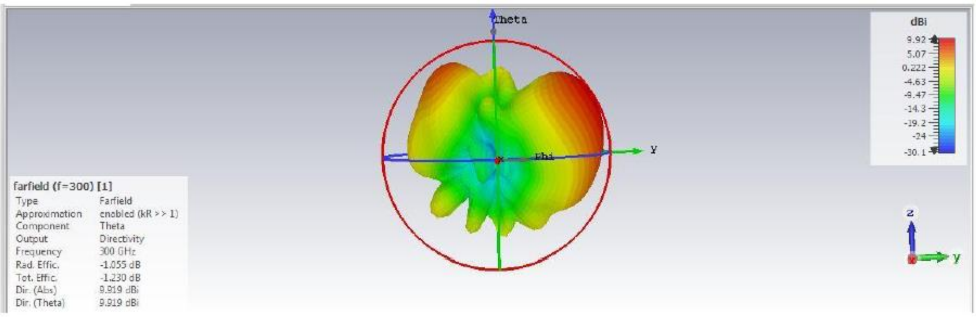


Figure 8: Gain of the antenna in the farfield

Figure 9 shows the 2D view gain in the farfield of the antenna. The maximum gain of the antenna was 9.92 dB. The half power (3 dB) beam width is 51.7 degrees.

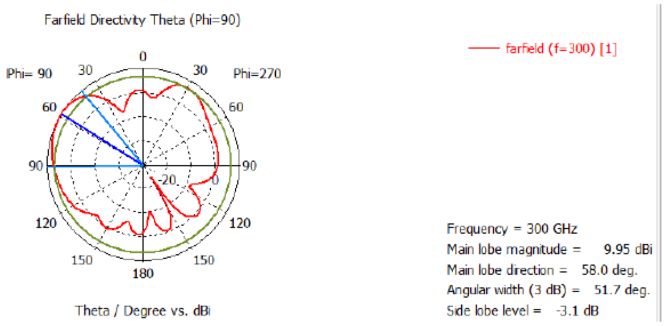


Figure 9: Farfield Directivity Theta

The antenna's S-parameter is shown in Figure 10. It radiated best at roughly 280 GHz to 500 GHz, where S11=10dB. Because S11 was beyond the -10dB limit, the antenna will transmit virtually nothing below 280 GHz.

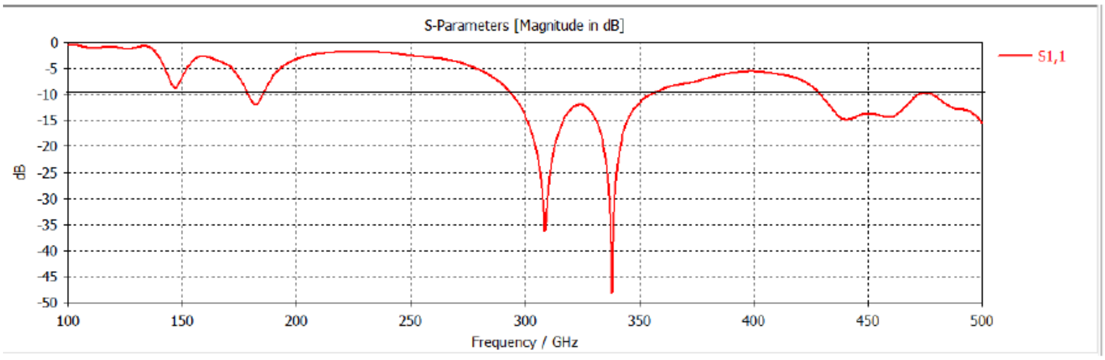


Figure 10: S-parameter of the antenna

The proposed antenna's Voltage Standing Wave Ratio (VSWR) vs frequency graph is shown in Figure 11. At 300 GHz, the VSWR must be at least 1.5, which was deemed adequate for most antenna applications.

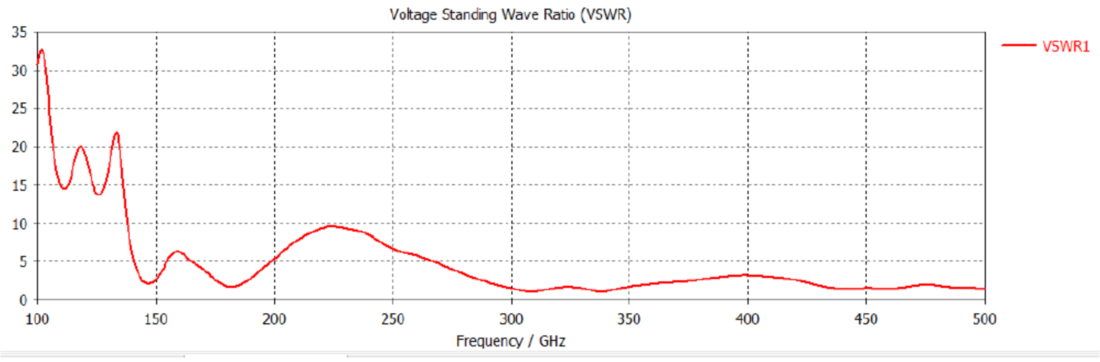


Figure 11: Voltage Standing Ratio (VSWR)

At a resonant frequency of 300 GHz, a microstrip patch antenna employing two different materials, graphene and carbon nanotubes (CNT), had been successfully constructed. The antenna had a good gain, with graphene gaining 9.06 dB and carbon nanotubes gaining 9.92 dB. (CNT). It gets close to match the outcomes. The antenna's VSWR was 1.013 for graphene and 1.5 for carbon nanotubes (CNT). The comparison of Graphene and Carbon Nanotubes performance as shown in Table 5.

Tables 5: Comparison of Graphene and Carbon Nanotubes

[redacted]	Graphene	Carbon Nanotubes
Maximum Gain of Antenna	9.06 dB	9.92 dB
Antenna Radiates	180 GHz – 350 GHz	280 GHz – 450 GHz
Bandwidth	180 GHz (Low end), 350 GHz (High end)	280 GHz (Low end), 450 GHz (High end), Multiband
VSWR (minimum at 300 GHz)	1.013	1.5

4. Conclusion

Graphene and carbon nanotubes were used to successfully create a microstrip patch antenna with a resonance frequency of 300 GHz (CNT) For graphene, the antenna had a gain of 9.06 dB, while for carbon nanotubes, it had a gain of 9.92 dB. (CNT). Graphene had a VSWR of 1.013, while carbon nanotubes had a VSWR of 1.5. (CNT). Graphene and carbon nanotubes can compete with metallic antennas for THz communication. This was just one of several steps in the development of graphene and carbon Nanotube antennas. Although the various antennas were not completely developed, they all have potential. There is a market for further research and manufacture of these antennas in the near future.

Acknowledgement

The authors would like to thank the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia for its support.

References

[1] F. T., Khandaker, M. R., & Imran, M. A. (2019, February). A Speculative Study on 6G. Retrieved January 15, 2021, from https://www.researchgate.net/ publication/ 331159423_A_Speculative_Study on 6g

[2] L. (1985, January). Antenna design and characterization based on the elementary antenna concept. Retrieved January 15, 2021, from

https://www.researchgate.net/publication /27347632_Antenna_design_and_characterization_based_on_the_elementary_antenna_concept

[3] V. R., & S. K. (2013, April). Design Of Carbon Nanotubes (CNT) Patch Antenna For WLAN Application. Retrieved January 15, 2021, from https://www.researchgate.net/publication/261216578_Design_Of_Carbon_Nanotubes_CNT_Patch_Antenna_For_WLAN_Application

[4] Ahmad Khan, M. W., M. H., T. B., M. A., L. S., & L. U. (2015, January). Fabrication and Characterization of Graphene Antenna for Low- Cost and Environmentally Friendly RFID Tags. Retrieved January 15, 2021, from https://www.researchgate.net/publication/283648544_Fabrication_and_Characterization_of_Graphene_Antenna_for_Low-Cost_and_Environmentally_Friendly_RFID_Tags

[5] Sa'don, S. H., Jamaluddin, M. H., Kamarudin, M. R., & F. A. (2018, December). Graphene Based Antenna Array for 5G Applications. Retrieved January 15, 2021, from https://www.researchgate.net/publication/336008114_Graphene_Based_Antenna_Array_for_5G_Applications

[6] M. K., M. A., H. A., & A. G. (2017). Terahertz Graphene-Based Reconfigurable Patch Antenna. Retrieved January 17, 2021, from http://www.jpier.org/PIERL/ pierl71/10.17081402.pdfZ

[7] A. S., & A. S. (2013, July 17). Design & Study of Carbon Nanotube Composite Based High Frequency Nano Antenna. Retrieved January 17, 2021, from https://www.ijert.org/design-study-of-carbon- nanotube-composite-based-high-frequency-nano-antenna

[8] V. S., Anuradha, M. S., & Douglas, S. P. (n.d.). Performance Analysis of Multiwalled Carbon Nanotube, Composite Multiwalled Carbon Nanotube, and Copper-Based Antenna in X-Band Applications. Retrieved January 17, 2021, from https://www.springerprofessional.de/en/performance-analysis-of- multiwalled-carbon-nanotube-composite-mu/18113274