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World Scientific News

An International Scientific Journal

WSN 125 (2019) 18-31 EISSN 2392-2192

# Design and analysis of a graphene-based Tera-Hertz antenna with lower complexities

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**ABSTRACT**

A graphene based rectangular patch antenna is designed at .979 THz with a return loss of -20 & VSWR of 2.1. A comparison of patch between graphene & its counterparts is investigated & found the superiority of graphene over PEC & Copper. This type of patch antenna can be used for future THz brain imaging.

***Keywords*: ** Graphene, PEC, THz, brain imaging

## 1. INTRODUCTION

Graphene is a flat mono-atomic layer of carbon atoms tightly packed in a two-dimensional honeycomb lattice and it has recently attracted the attention of the research community due to its novel mechanical, thermal, chemical, electronic and optical properties [1-3]. Due to its unique characteristics, graphene has given rise to a plethora of potential applications in many diverse fields, ranging from ultra-high-speed transistors [4] to transparent solar cells [5].

Graphene enabled wireless communications constitute a novel paradigm which has been proposed to implement wireless communications at the nano scale. Indeed, graphene based nano antennas just a few micrometers in size have been predicted to radiate electromagnetic

( Received 04 March 2019; Accepted 20 March 2019; Date of Publication 21 March 2019 )

waves at the terahertz band [6-13], at a dramatically lower frequency and with a higher radiation efficiency with respect to their metallic counterparts.

Moreover, the progress in the development of graphene-based components shows that the high electron mobility of graphene makes it an excellent candidate for ultra-high-frequency applications [14].

## 2. PATCH ANTENNA PARAMETER CALCULATION

The patch dimension has been calculated using the following equation:

### i. Patch Width

$$w = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \quad \text{------------------------------------- (2.1)}$$

$v_0$ = The velocity of light.
$\varepsilon_r$ = Dielectric constant of substrate.

### ii. Effective dielectric constant of the rectangular microstrip patch antenna

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+\frac{12h}{w}}}\right) \quad \text{------------------------- (2.2)}$$

### iii. Patch Length

$$L = L_{eff} - 2\Delta L \quad \text{--------------------------------- (2.3)}$$

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} \quad \text{----------------------------------- (2.4)}$$

### iv. Calculation of length extension

$$\Delta L = 0.412h\frac{(\varepsilon_{eff}+0.3)(\frac{w}{h}+0.264)}{(\varepsilon_{eff}-0.258)(\frac{w}{h}+0.8)} \quad \text{------------------(2.5)}$$

### v. Inset Feed

$$50 = R_{in}\left(\cos\left(\frac{\pi}{L}y_0\right)\right)^2 \quad \text{------------------------------ (2.6)}$$

where: $R_{in}$ = The input impendence at the leading radiating edge of the patch. While 50 (Ω) is the desired impendence.

$$R_{in} = 90\frac{\varepsilon_r^2}{\varepsilon_r-1}\left(\frac{L}{W}\right)^2 \quad \text{-------------------------------- (2.7)}$$

The width of the Quarter wave line is given by

$$Z_T = \frac{60}{\sqrt{\varepsilon_r}} \ln(\frac{8d}{w_T} + \frac{w_T}{4d}) \quad \text{--------------------------------- (2.8)}$$

where: $z_T$ is calculated as:

$$z_T = \sqrt{50 \times Z_a} \quad \text{-------------------------------------- (2.9)}$$

The length of Quarter line

$$L_{T=} \frac{\lambda}{4} = \frac{\lambda_0}{4\sqrt{\varepsilon_{eff}}} \quad \text{-------------------------------------- (2.10)}$$

The width of 50Ω line is given by:

$$z_0 = \frac{120\pi}{\sqrt{\varepsilon_r}\left[1.393+\frac{2}{3}\ln(\frac{w}{h}+1.444\right)+\frac{w}{h}} \quad \text{--------------------------- (2.11)}$$

## 3. RESULT / SIMULATION

### 3. 1. Directivity

Directivity of an antenna is defined as "the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions. The average radiation intensity is equal to the total power radiated by the antenna divided by 4π. If the direction is not specified, the direction of maximum radiation intensity is implied." [15] Stated more simply, the directivity of a non-isotropic source is equal to the ratio of its radiation intensity in a given direction over that of an isotropic source [16]. In mathematical form, it can be written as:

$$D = U/U_0 = 4\pi U / P_{rad} \quad \text{--------------------------------- (2.18)}$$

### 3. 2. Gain

Gain of an antenna (in a given direction) is defined as "the ratio of the intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotopically. The radiation intensity corresponding to the isotopically radiated power is equal to the power accepted (input) by the antenna divided by 4π in equation form this can be expressed as [17]:

$$\text{Gain} = 4\pi \ \frac{\text{radiation intensity}}{\text{total input(accepted power)}} .$$

### 3. 3. Return Loss

Return loss is a measure of the effectiveness of power density from a transmission line to a load such as an antenna. If the power incident on the Antenna-Under-Test (AUT) is $P_{in}$ and the reflected back to the source is $P_{ref}$, the degree of mismatch between the incident and reflected power in the travelling waves is given by ration $P_{in} / P_{ref}$. The higher this power ratio is, the better the load and line are matched. Expressed in dB, return loss is defined as

$$RL = 10 \log_{10} \left(\frac{P(input)}{P(reference)}\right) \text{dB} \qquad \text{-------------------- (2.19)}$$

Which is a positive quantity if $P_{ref} < P_{in}$. Stated another way, RL is the difference in dB between the power sent towards AUT and the power reflected. It is positive non-dissipative term representing the reduction in comparison with the incident one [18]. This is the situation for a passive AUT. A negative return loss is possible with active devices.

### 3. 4. Voltage Standing Wave Ratio

VSWR stands for Voltage Standing Wave Ratio, and is also referred to as Standing Wave Ratio (VSWR). VSWR is a function of the reflection coefficient, which describes the power reflected from the antenna. If the reflection coefficient is given by s-11 or reflection coefficient or return loss, then the VSWR is defined by the following formula [12, 19-22]:

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \qquad \text{---------------------------------- (2.20)}$$

The VSWR is always a real and positive number for antennas. The smaller the VSWR is, the better the antenna is matched to the transmission line and the more power is delivered to the antenna. The minimum VSWR is 1.0. In this case, no power is reflected from the antenna, which is ideal [23].

## 4. SIMULATION OUTPUT

### 4. 1. Antenna design using PEC

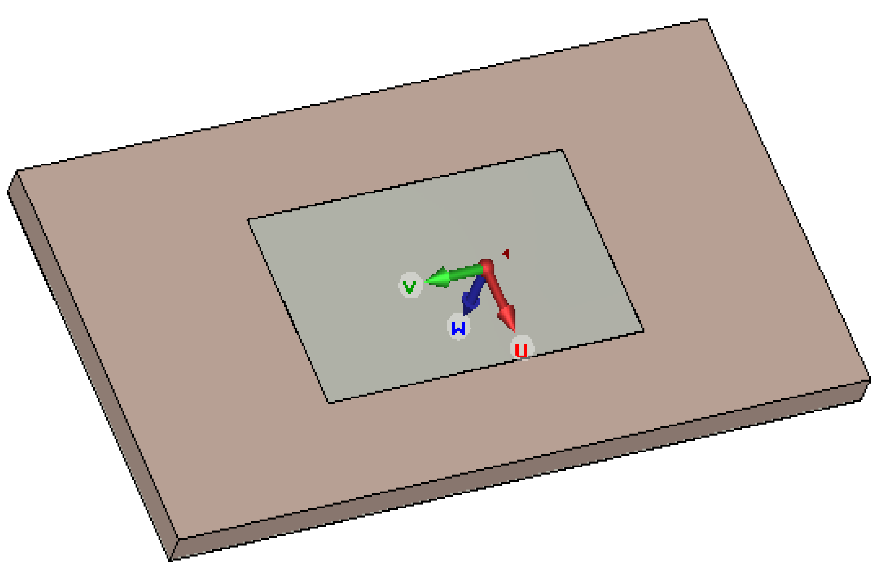


**Figure 1.** Rectangular patch with PEC

### 4. 2. Return Loss for PEC

Substrate Height (h = 80 μm) and Substrate Material (Rexolite loss)

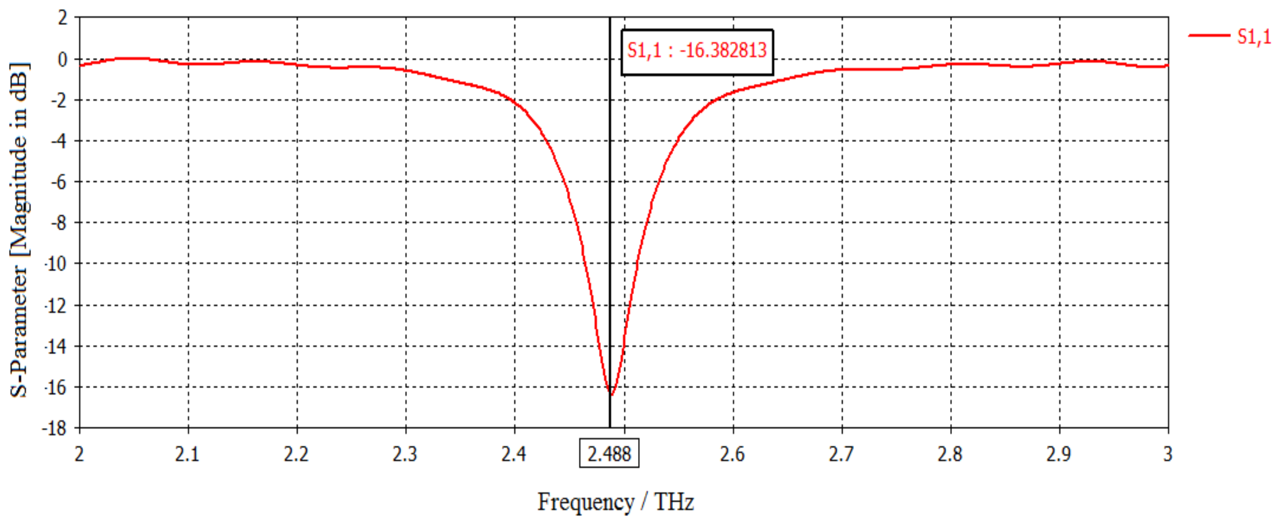


**Figure 2(a).** S-parameter vs THz plot

### 4. 3. Voltage standing wave ratio (VSWR)

Substrate Height (h = 80 μm) and Substrate Material (Rexolite lossy)

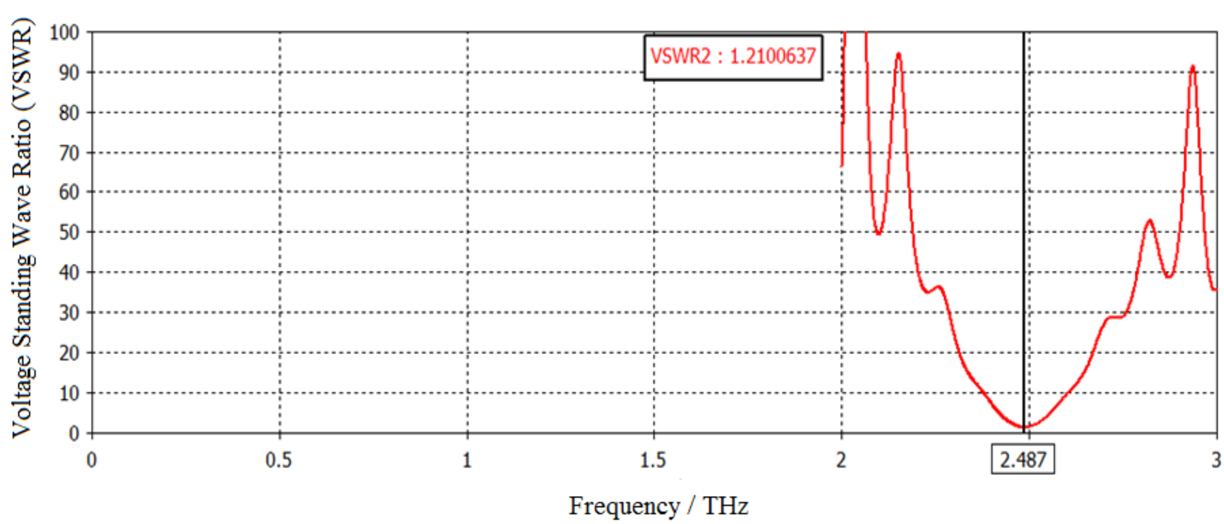


**Figure 2(b).** Voltage standing wave ratio patch with PEC

## 4. 4. Gain and Directivity

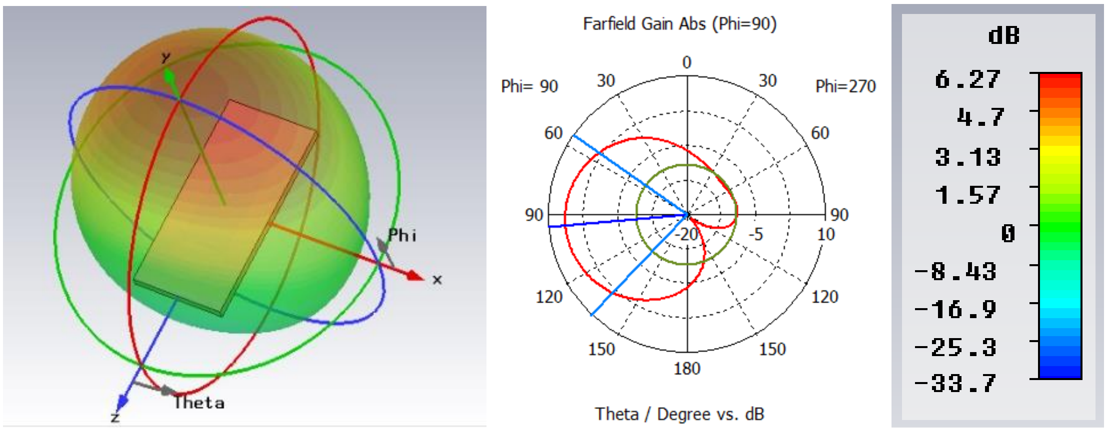


**Figure 3.** 3-D and polar view of the gain of the rectangular patch antenna.

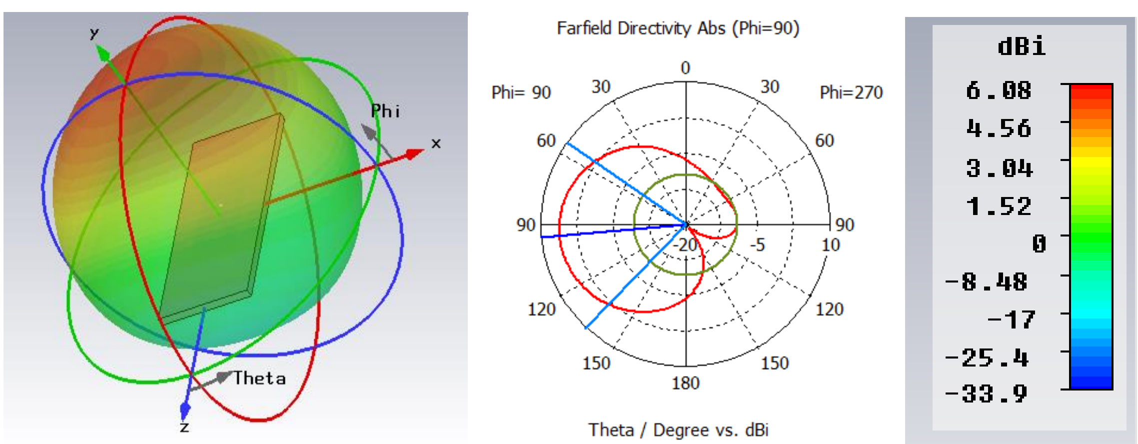


**Figure 3(b).** 3-D and polar view of the directivity of the rectangular antenna.

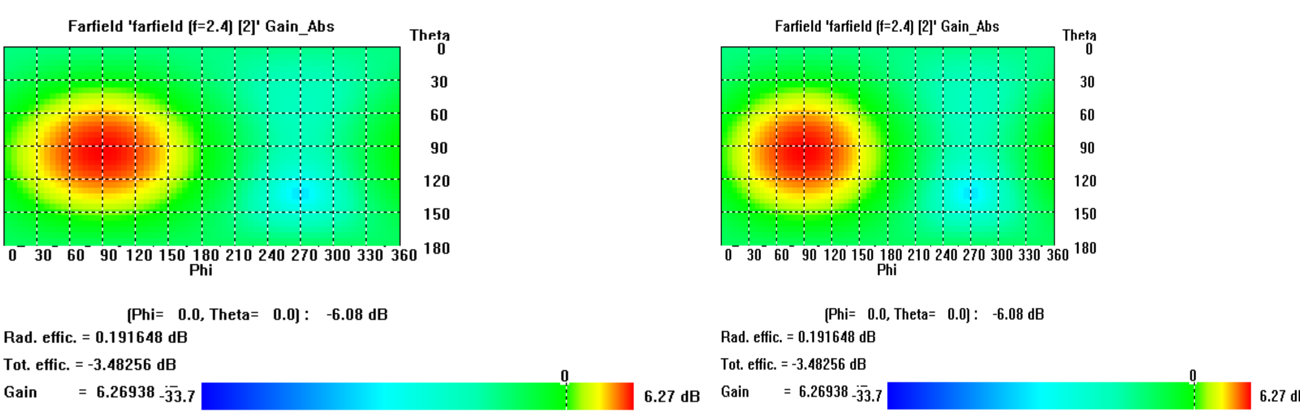


**Figure 4.** 2D view of directivity and gain of rectangular antenna

### 4. 5. Rectangular Microstrip Patch Antenna with Copper (annealed)

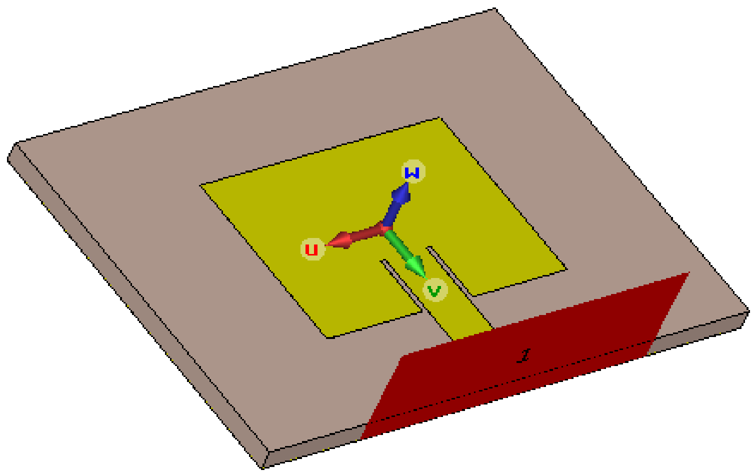


**Figure 5.** Rectangular microstrip patch antenna with copper (annealed).

### 4. 6. Return Loss for copper (annealed)

Substrate Height (h = 51 μm) and Substrate Material (FR4 lossy)

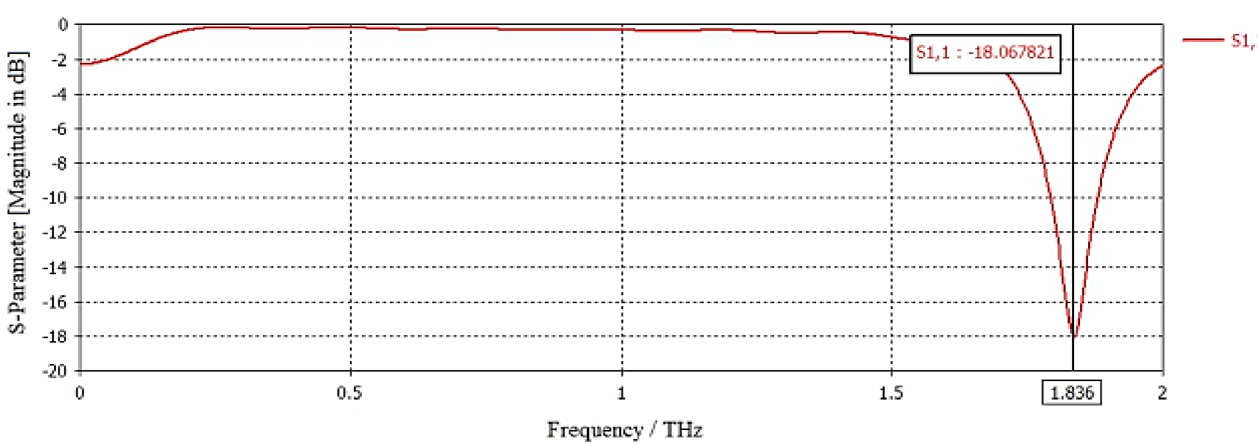


**Figure 6.** S-parameter vs THz plot for copper (annealed)

### 4. 7. Voltage standing wave ratio (VSWR)

Substrate Height (h =51μm) and Substrate Material (FR4 lossy)

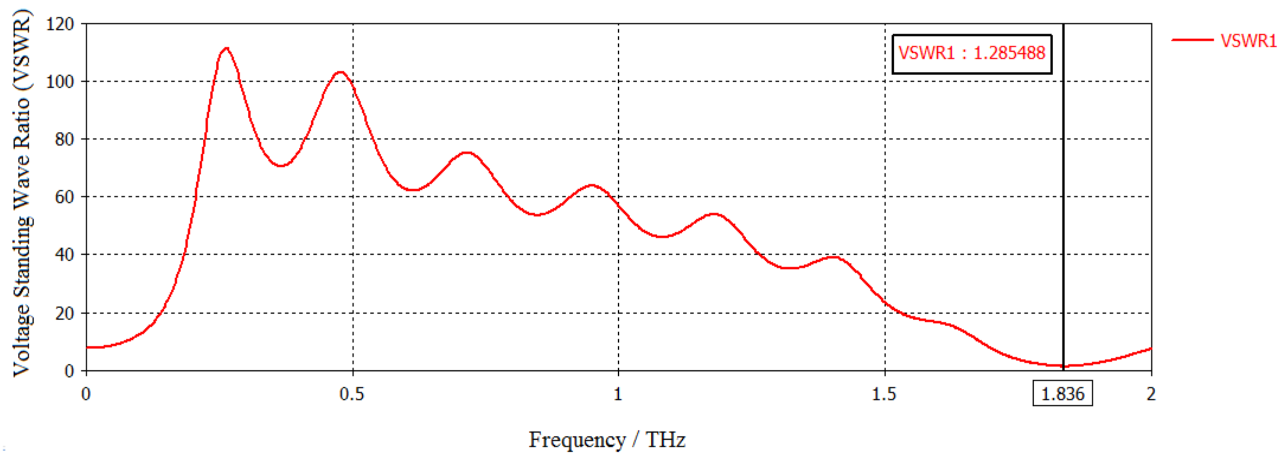


**Figure 7.** VSWR vs THz plot for copper (annealed)

## 4. 8. Gain and Directivity

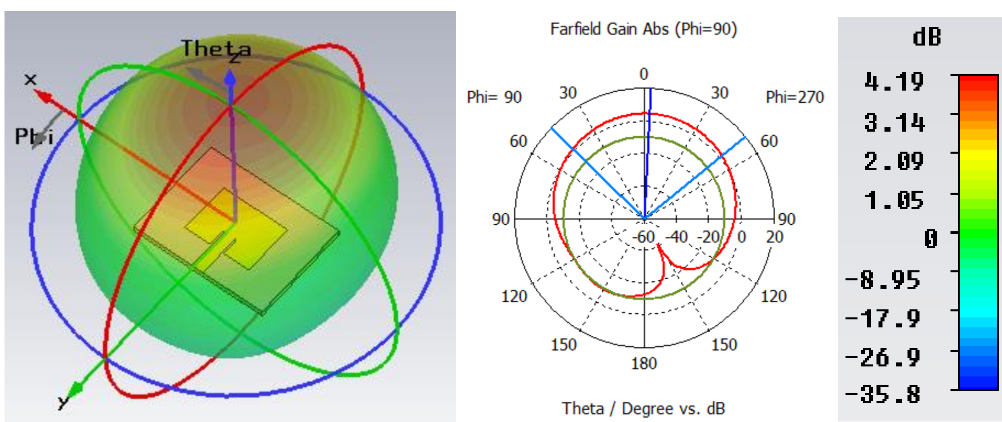


**Figure 8(a).** 3-D and polar view of the gain of the Microstrip patch antenna.

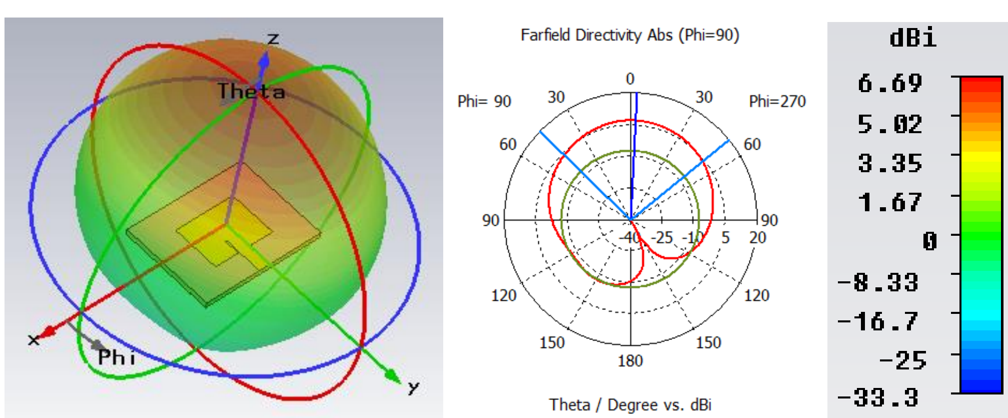


**Figure 8(b).** 3-D and polar view of the directivity of the Microstrip patch antenna.

### 4. 9. Rectangular patch antenna using Graphene material

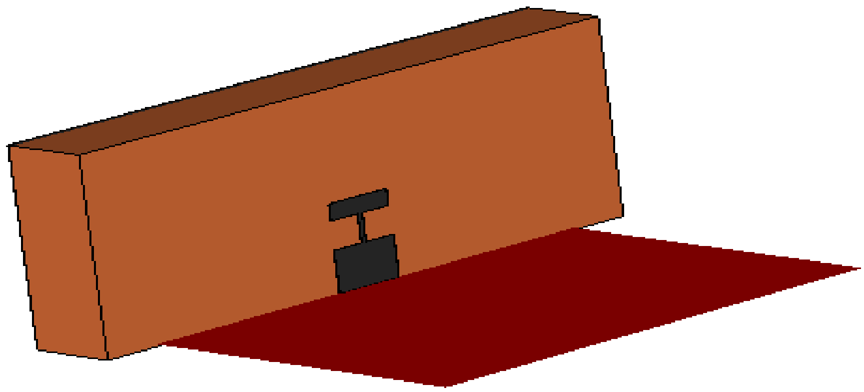

**Figure 9.** Rectangular microstrip patch antenna with graphene.

### 4. 10. Return Loss for Graphene

The return loss is -20.182281 dB.

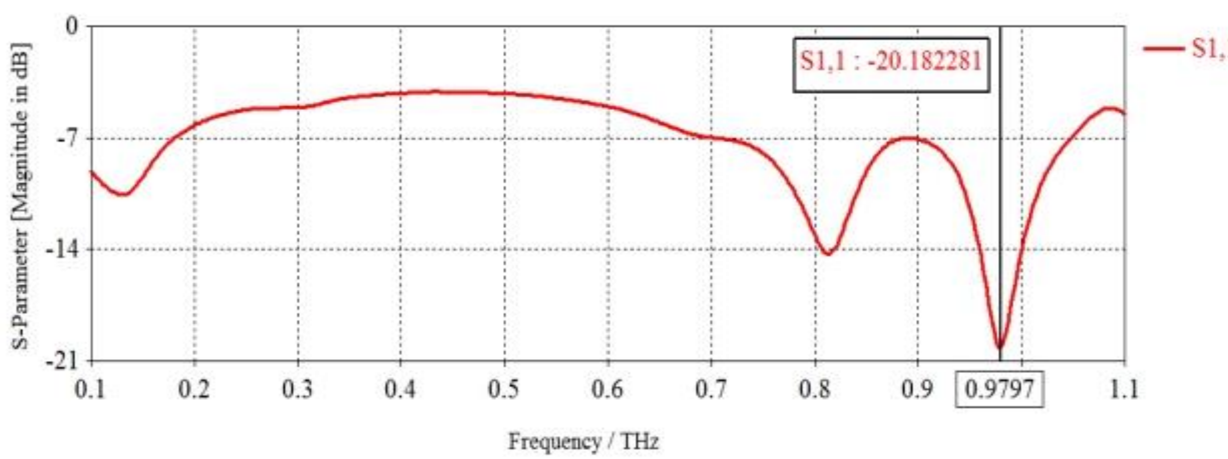


**Figure 10(a).** Return loss in THz band for graphene.

### 4. 11. Voltage standing wave ratio (VSWR)

The VSWR of the antenna is found 1.2171063.

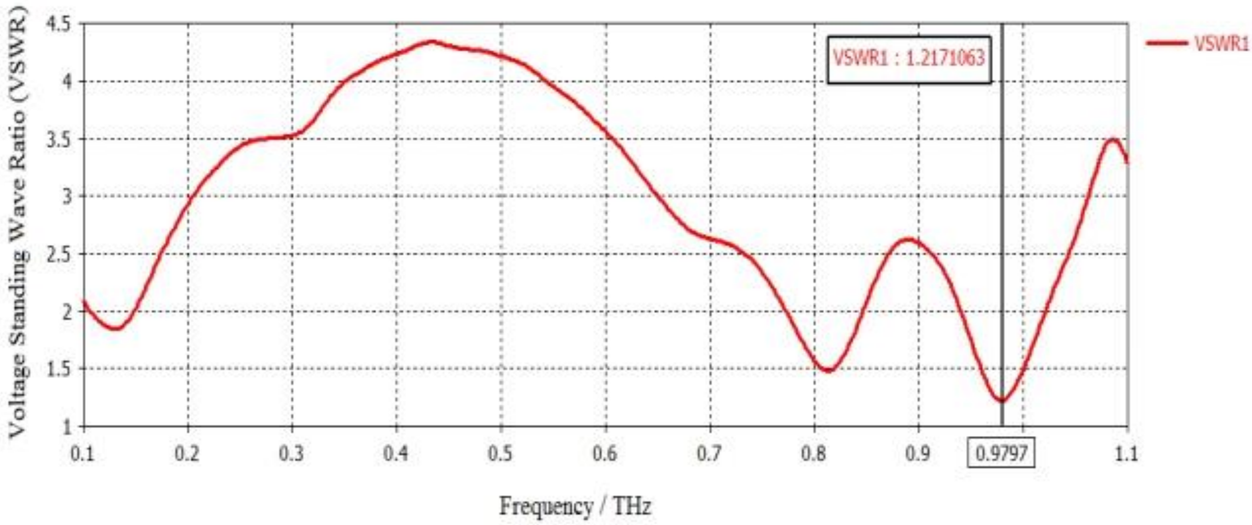


**Figure 10(b).** VSWR in THz band for graphene.

## 4. 12. Gain and Directivity

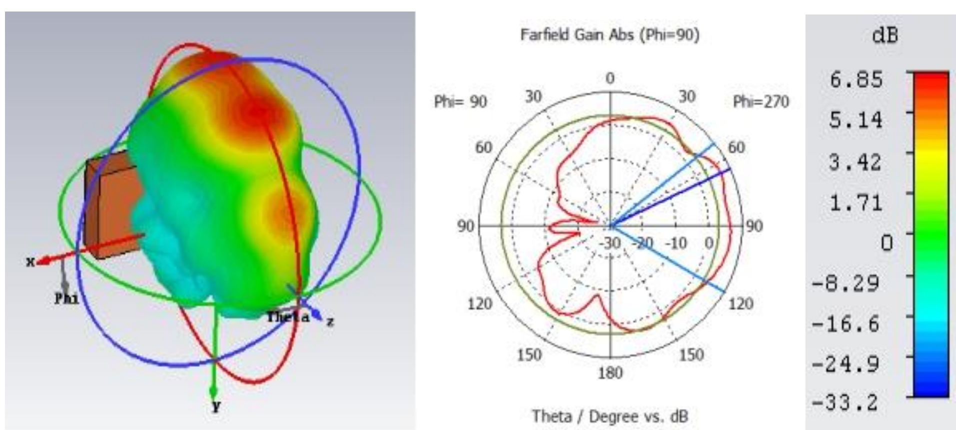


**Figure 11(a).** 3D and Polar view of the gain of the antenna.

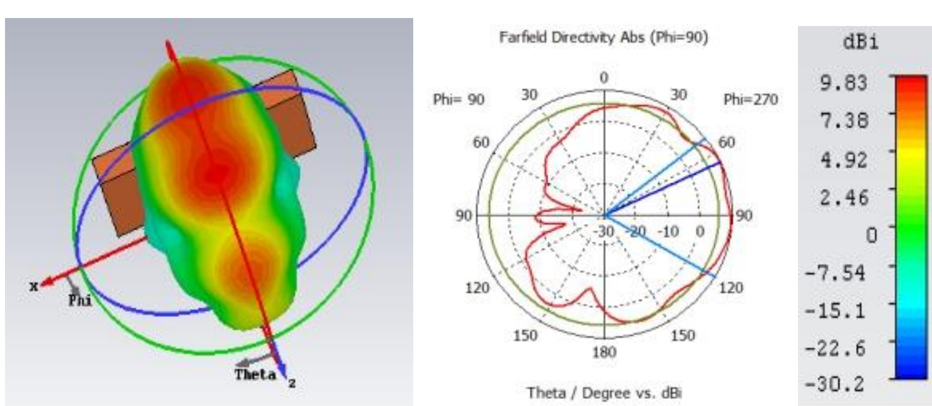


**Figure 11(b).** 3D and Polar view of the directivity of the antenna.

## 4. 13. Comparison Plot

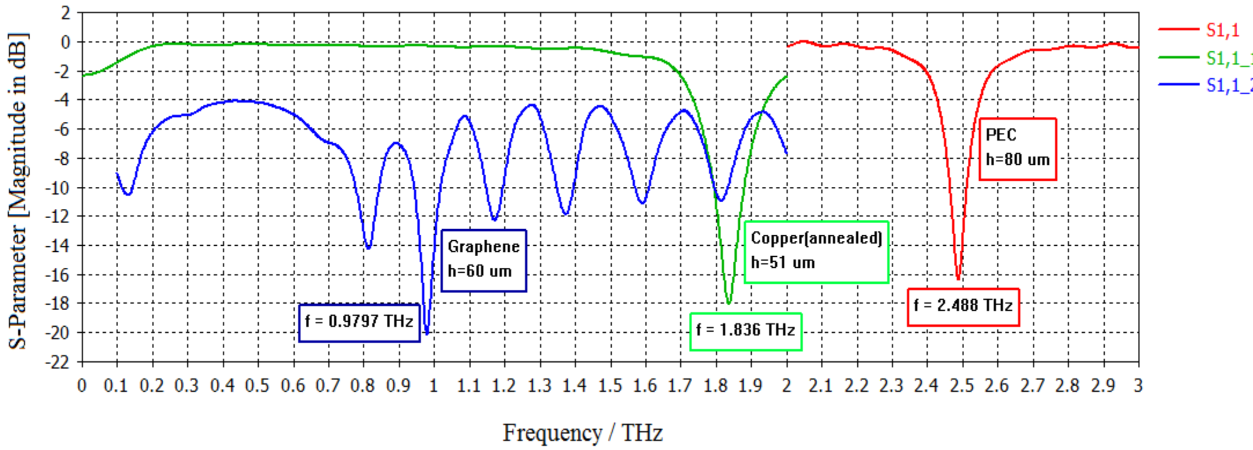


**Figure 12.** Comparison of Return loss among different Patch material

The simulation results are given in the following table:

**Table 1.** Simulation results of the rectangular antennas.

| Contents | Antenna with PEC | Antenna with Copper(annealed) | Antenna with Graphene |
|---|---|---|---|
| S-parameter | -16.382813 dB | -18.067821 dB | -20.182281 dB |
| VSWR | 1.2100637 | 1.285488 | 1.2171063 |
| Gain | 6.27 dB | 4.19 dB | 6.85 dB |
| Directivity | 6.08 dBi | 6.69 dBi | 9.83 dBi |

## 5. ANALYSIS

The return loss of graphene patched antenna is better than copper & PEC. The Voltage Standing Wave ratio (VSWR) is almost same for PEC & graphene but the directivity & gain is far better than Copper & PEC. So, graphene is better than copper & PEC in the THz region.

## 6. CONCLUSIONS

We have shown that antennas on graphene at THz frequencies display good values of radiation efficiencies and gain of antenna. The expectation to control the antennas in an array using the low and high resistivity states of the graphene to back or top gates allows to implement desirable radiation activity with decreasing lateral lobes, such that the THz electromagnetic energy is concentrated in a single main lobe.

## Acknowledgement

The authors are very grateful to the Dept. of Electrical & Electronic Engineering along with the Dept. of Mechanical Engineering, RUET, Rajshahi, Bangladesh for supporting the needed simulation environment.

## Biography

Md. Mashrur Islam has been graduated from the Dept. of Electrical & Electronic Engineeringing, RUET, Rajshahi. He has deep research interest in PEC Antenna design, Graphene material and wireless communications. He is currently working as an Operations Engineer in NEPC Consortium Power Ltd. (A subsidiary of Pendekar Energy Ltd.). He has published some of his researches in internation journals.

Saleh Ahmed is an undergraduate student of Mechanical Engineering, RUET, Bangladesh. He was born and brought up in Khulna. He has a deep interest in Wireless secure communications, Renewable Energy Resources, Python Language Coding. Currently he is serving voluntarily for various research organizations as an associate. He has attended various local seminars and conferences and also published his researches in some international journals.

Nadim Mahmud is an undergraduate student of Mechanical Engineering, RUET, Bangladesh. He is an enthusiastic man and wildlife photography is his hobby. He has a cherished interest in 3D printing, CAD design and Thermal Simulation.

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