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Graphene-Based Materials for Microstrip Patch Antenna

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Abstract—Microstrip patch antennas are becoming increasingly relevant because of their advantages such as light weight, low costs, and ease of fabrication. To enhance the performance of an antenna, graphene was included into the fabrication of the microstrip patch antenna. Because of its numerous excellent characteristics, graphene has gained attention in recent years as a leading material. In this research, a microstrip patch antenna based on graphene was fabricated and tested at 5 GHz. The fabrication started with the production of graphene paste and was screen printed onto RT duroid 5880 substrates. To verify the binding between the graphene paste and the substrate, an adhesion test was performed on the finished graphene-based patch antenna using the Scotch tape method. The performance of fabricated antenna was measured using vector network analyzer (VNA) which includes return loss and bandwidth. The findings of the measurements were compared with the simulation results that were generated by the High Frequency Structure Simulator (HFSS). The return loss of the graphene-based antenna was measured to be −17.6314 dB, which is a little bit lower than the simulated value of −18.0597 dB that was generated by the HFSS software. The calculated bandwidths for simulated and fabricated graphene-based patch antennas were found at 0.156 GHz and 0.2974 GHz, respectively. Based on the findings, it can be concluded that the return loss result indicates that the fabricated graphene-based patch antenna agrees well with the simulated patch antenna, although the fabricated patch antenna has a greater bandwidth than the simulated antenna.

1. INTRODUCTION

An antenna is a device that sends or receives electromagnetic waves. Antennas are crucial components of every wireless system. Because of its attractive properties, a microstrip patch antenna is the most commonly used in wireless transmission technology. The microstrip patch antenna is small in size, light in weight, and simple to construct [1]. Besides, it also delivers great performance and cheap cost in manufacture [2]. A device that either transmits or receives electromagnetic waves is known as an antenna.

An antenna is a transducer that generates an electromagnetic field in space that comprises electric and magnetic fields moving at right angles to one another from the voltage and current on a transmission line [3]. The antenna is a vital part of every wireless network. As a result of its advantageous characteristics, the microstrip patch antenna has become the standard in wireless transmission technology, particularly for the usage in microwave systems. The microstrip patch antenna was light weight, portable, and simple to construct [1]. Additionally, antennas provide excellent performance at low manufacturing costs [2].

Microstrip antennas are compact, light weight, and conformable to both planar and non-planar surfaces. Using contemporary printed circuit technology, their production is easy and inexpensive. Low efficiency, limited bandwidth of less than 5 percent, and low RF power owing to the tiny gap between

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the radiation patch and the ground plane are the primary drawbacks of patch antennas. To overcome those drawbacks in patch antenna, the material choices in the fabrication of circuit play an important role in the performance of antenna. Typically, a metallic patch is formed of a thin copper foil coated with a metal that is resistant to corrosion, such as gold, tin, or nickel.

Graphene is the thinnest two-dimensional (2D) layer of carbon atoms in which the carbon atoms are arranged in a honeycomb lattice [4]. Due to its high charge of mobility, graphene possesses a high conductivity [5]. Extremely high sensitivity and thermoelectric current effect are two additional benefits of graphene [6]. Because of its outstanding and surprising qualities, graphene has piqued the interest of researchers and scientists. There are numerous technological applications for graphene, including supercapacitors, stretchable transistors, organic photovoltaics, light-emitting diodes (LEDs), thermal conduction, and others [7, 8].

2. ANALYSIS AND DESIGN

2.1. Conductivity of Graphene

The conductivity of graphene is frequency dependent and can be altered as the conductivity of a metal or semiconductor. It is an infinitesimally thin layer of carbon linked between two distinct media in a honeycomb lattice pattern. The surface conductivity is a function of frequency, ω, chemical potential, μ_c, scattering rate, Γ, and temperature, T, which can be modelled by Kubos formula whose surface conductivity consists of two terms: intraband conductivity and interband conductivity [9]. The intraband conductivity can be evaluated as

$$\sigma_{\text{intra}} = -j\frac{e^2 K_B T}{\pi\hbar^2(\omega - j2\Gamma)}\left[\frac{\mu_c}{K_B T} + 2\ln\left(e^{-\mu_c K_B T + 1}\right)\right], \tag{1}$$

and the interband conductivity is

$$\sigma_{\text{inter}} \simeq -j\frac{e^2}{4\pi\hbar}\ln\left[\frac{2|\mu_c| - (\omega - j2\Gamma)\hbar}{2|\mu_c| + (\omega - j2\Gamma)\hbar}\right] \tag{2}$$

where K_B is the Boltzmann constant, $\hbar$ the Planck's constant, e the electron charge, ω the angular frequency, Γ the scattering rate, T the temperature, and μ_c the chemical potential.

2.2. Antenna Design

The substrate's thickness, dielectric constant, and operation frequency are the three variables that must be determined before designing a microstrip patch antenna [10]. The parameters used were 1.57 mm thickness, 2.2 dielectric constant, and 5 GHz operating frequency. Figure 1 shows that the configuration of rectangular microstrip patch antenna consists of a ground plane, patch conductor, and substrate.

The predefined parameters of patch antenna such as length of patch, L, width of patch, w, length of ground plane, L_g, and width of ground plane, W_g, need to be determined before simulation or fabrication process.

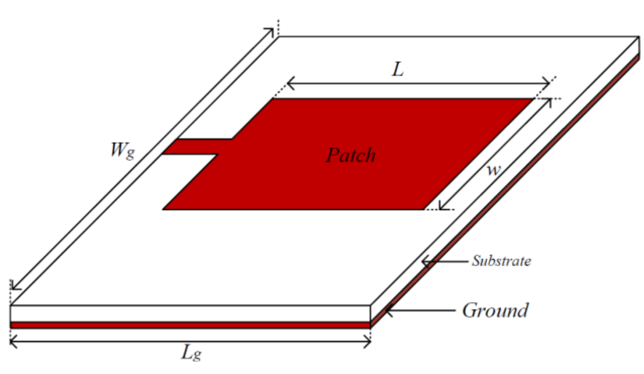


Figure 1. Configuration of a rectangular microstrip patch antenna.

The width, w, of the microstrip patch antenna was obtained from Equation (3)

$$w = \frac{c}{2f_o}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{3}$$

where f_o = operation frequency, c = speed of light, ε_r = dielectric constant of the substrate.

In order to determine the length of the patch, L, we need to perform a few additional computations. It is necessary to start by figuring out the dielectric constant. In Equation (4), we may find the dielectric constant of the substrate.

$$\varepsilon_{\mathit{eff}} = \frac{\varepsilon' + 1}{2} + \frac{\varepsilon' - 1}{2}\left[1 + 12\left(\frac{h}{w}\right)\right]^{-1/2} \tag{4}$$

where h = thickness of the substrate, $\varepsilon_{\mathit{eff}}$ = effective dielectric constant of the substrate. The value for effective length can be calculated by using Equation (5):

$$L_{\mathit{eff}} = \frac{c}{2f_o\sqrt{\varepsilon_{\mathit{eff}}}} \tag{5}$$

The following step is to compute the length extension, which is denoted by ΔL. Because of fringing effects, the microstrip antenna gives the impression of being far bigger electrically than its real physical dimensions. Equation (6), which gives the length extension, is as follows:

$$\Delta L = 0.412h\frac{(\varepsilon_{\mathit{eff}} + 0.3)\left(\frac{w}{h} + 0.264\right)}{(\varepsilon_{\mathit{eff}} - 0.258)\left(\frac{w}{h} + 0.8\right)} \tag{6}$$

The actual length of the patch, L, is obtained by Equation (7):

$$L = L_{\mathit{eff}} - 2\Delta L \tag{7}$$

In order for patch antennas to function properly, the design process must begin with a finite ground plane. Equations (8) and (9) can be used to determine the length and width of the ground plane, respectively.

$$L_g = 6h + L \tag{8}$$
$$W_g = 6h + w \tag{9}$$

where w = width of the patch antenna, L = length of the patch antenna, W_g = width of ground plane, L_g = length of ground plane.

All the predefined parameters were calculated using MATLAB software, and the data are tabulated in Table 1.

Table 1. Predefined parameter for patch antenna design.

Parameter	**Value**
Patch Length, L	34 mm
Patch Width, W	46 mm
Ground Length, Lg	65 mm
Ground Width, Wg	55 mm

The obtained predefined parameters were used in simulation of patch antenna using a commercial High Frequency Structure Simulator (HFFS) software. The commercial finite element technique for electromagnetic structure from Ansys Corporation is one of the few commercial tools that is used for the antenna design purpose. The patch antenna was designed to be positioned at origin coordinates x-y plane while the height of the substrate lies in z-direction. The geometric design is illustrated in Figure 2. The patch of the designed antenna is 34 mm in length and 46 mm in width, while the substrate is 65 mm in length and 55 mm in width, as indicated in Table 1, which is based on a set of predefined parameters. The entire structures are positioned on an endless ground plane.

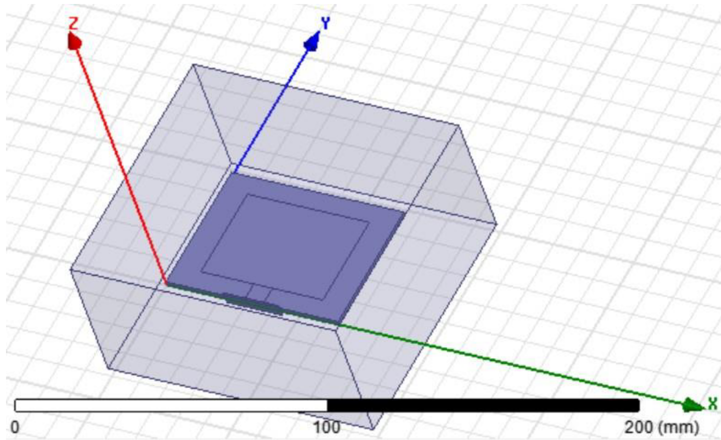


Figure 2. Patch antenna model from the HFSS-13 programme.

In antenna design, the antenna's shape must be selected. The High Frequency Structure Simulator (HFFS) software may accommodate many geometries [11]. One of the most essential parts of a microstrip patch antenna is a dielectric substrate that has a ground plane on one side and a radiating patch on the other as illustrate in Figure 1. The patch can have any form and is often constructed of conductive materials like copper or gold. In this study, a graphene material is chosen since it has a good electrical and thermal conductivity [14]. Typically, the feed lines and radiating patch are photo etched onto the dielectric substrate.

3. MATERIALS

Graphite (C, MW = 12.011 g/mol), potassium permanganate ($KMnO_4$, MW = 158.034 g/mol), sulphuric acid (H_2SO_4, MW = 98.079 g/mol), phosphoric acid (H_3PO_4, MW = 97.994 g/mol), potassium permanganate ($KMnO_4$, MW = 158.034 g/mol), 35% hydrogen peroxide (H_2O_2, MW = 34.0147 g/mol), ascorbic acid ($HC_6H_7O_6$, MW = 176.12 g/mol), M-xylene ($C_6H_4(CH_3)_2$, MW = 106.16 g/mol) and α-terpineol ($C_{10}H_{18}O$, MW = 154.25 g/mol), linseed oil, RT duroid 5880 substrates, and SMA connector.

4. CIRCUIT FABRICATION

The fabrication procedure of the graphene patch antenna circuit was started from the production of graphene powder as mentioned in previous paper [12]. The graphene powder was produced from graphite powder as starting material. Graphite was synthesized to form graphene oxide (GO) using Improved Hummer method. In an ice bath, a conical flask containing sulphuric acid (H_2SO_4), phosphoric acid (H_3PO_4), graphite (G), and potassium permanganate ($KMnO_4$) was agitated and heated for 12 hours. The combination solution was then combined with distilled water and 35% hydrogen peroxide (H_2O_2) to make GO solution. Ascorbic acid was utilised in the conversion of GO to graphene. Ascorbic acid was added to the GO solution from a prior synthesis. The mixture was heated before being centrifuged. As the reaction's supernatant decayed, solid graphene was created. The solid graphene was heated in an oven at 40°C for 24 hours before being ground into powder for 2 hours. The graphical representation of the methodology of this study is illustrated in Figure 3. First, the graphene powder was produced using an improved version of the hummer‘s method, which involved the conversion of graphite as starting material to graphene oxide. Ascorbic acid was utilised in a reduction process to create graphene from graphene oxide. The acquired graphene was dried in an oven, centrifuged until pH 5, then ground up till powder was formed.

The obtained graphene powder was used to make binder for graphene thick film paste. The binder was made by blending linseed oil, m-xylene, and α-terpineol. The mixture was stirred at 40°C for two hours. The binder was combined with graphene powder at a ratio of 30 : 70 powder to binder. Using

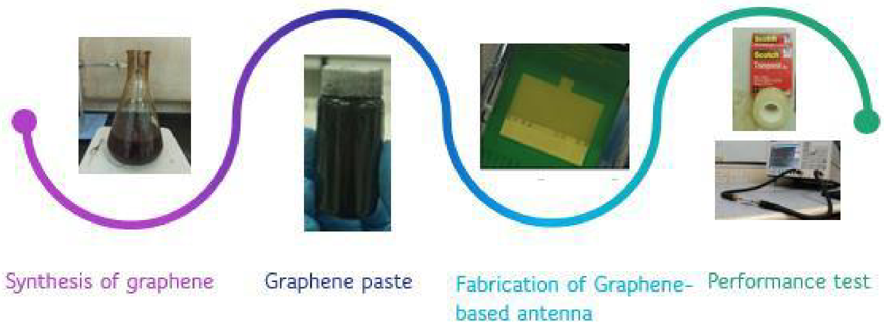


Figure 3. Graphical representation of graphene-based patch antenna fabrication.

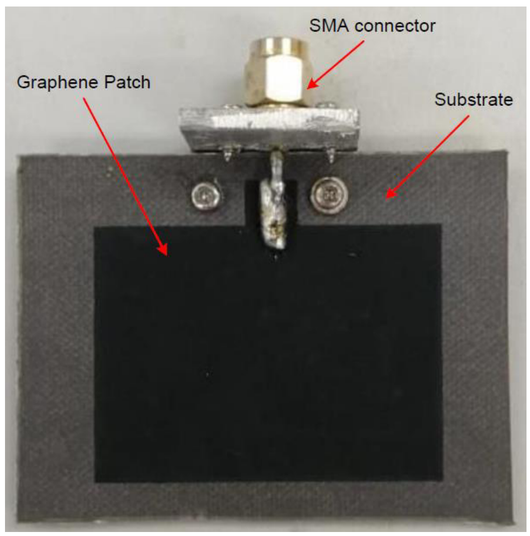


Figure 4. Fabricated graphene-based microstrip patch antenna.

a vortex mixer, the mixture was agitated for 1 hour to create a homogenous paste. To create a patch antenna circuit, a graphene thick film paste was screen-printed on top of RT duroid 5880 substrates ($\varepsilon_r = 2.2$ and thickness $h = 1.57$ mm). The circuit was then dried for 30 minutes at 80°C and followed by sintering process for 3 hours at 300°C in an oven. The graphene-based patch antenna circuit was left 24 hours at room temperature. Finally, as shown in Figure 4, patch antenna circuit was attached with an SMA connector in order to evaluate its performance using vector network analyzer (VNA).

5. CIRCUIT TESTING AND PERFORMANCE

5.1. Return Loss

Return loss is a logarithmic ratio expressed in decibels (dB) that compares the power emitted by the antenna to the power delivered into it through the transmission line [13]. The acceptable return loss value for antenna should be greater than 10 dB (below −10 dB), which corresponds to 10% reflected power. But typical antenna system requires the return loss greater than 15 dB, meaning that the maximum allowed reflected power at any frequency in the range is 3.2%. The resonant frequencies of simulated and fabricated patch antennas are shown in Figure 5. As can be seen in the figure, the highest return loss of simulated antenna is −18.0497 dB at resonant frequency of 5.0 GHz, meaning that the maximum allowed reflected power at 5 GHz of simulated antenna is 1.57%. The return loss for fabricated graphene-based antenna is −17.6314 dB as shown in Figure 5 which is greater than 15 dB, meaning that

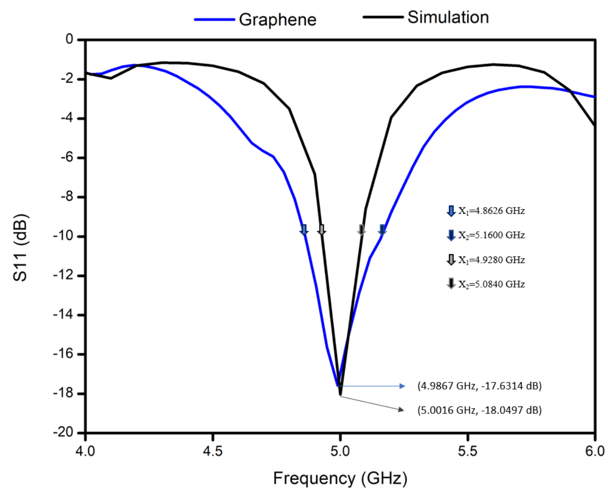


Figure 5. Return losses of the simulated and fabricated graphene-based patch antennas.

the reflected power by graphene-based antenna is 1.73%. In comparison to the simulation, the measured return loss of the graphene-based antenna is −17.6314 dB, which is slightly lower from the −18.0497 dB as simulated by the HFSS software. Compared to the simulation results, in which only 1.57% of the power is reflected, the power reflected by the graphene-based antenna is slightly higher at 1.72%. A higher return loss indicates that the circuit operates more efficiently. Based on the measured return loss, the simulated circuit performed better than its graphene-based counterpart since the simulation did not take into account the structural properties of graphene. The comparison data of return loss and bandwidth for simulated and fabricated patch antenna are shown in Table 2.

5.2. Bandwidth

Bandwidth is the difference between the upper and lower frequencies in a continuous band of frequencies. The bandwidths for both simulated and fabricated patch antennas were determined at −10 dB which is at 10% reflected power, the accepted standard for antenna design. Figure 5 depicts the −10 dB notation for the lower frequency as X_1 and the upper frequency as X_2. The calculated bandwidths for simulated and fabricated graphene-based patch antennas were found at 156 MHz and 297.4 MHz, respectively. It is evident that the fabricated graphene-based patch antenna performed well in comparison to the simulated patch antenna with higher bandwidth due to the limitation of the software to consider the structural properties of the graphene. This was shown by the observation that the simulated patch antenna had a smaller performance bandwidth than the fabricated graphene-based patch antenna. The comparison results of fabricated and simulated antennas in terms of return loss and bandwidth are tabulated in Table 2.

Table 2. Comparison result for graphene and simulation patch antenna circuit.

	Graphene	**Simulation**
Return Loss	−17.6314 dB (4.9867 GHz) 1.73% power reflected	−18.04 97 dB (5.0016 GHz) 1.57% power reflected
Bandwidth at −10 dB	0.2974 GHz (297.4 MHz) $X_1 = 4.8626$ GHz $X_2 = 5.1600$ GHz	0.1560 GHz (156 MHz) $X_1 = 4.9280$ GHz $X_2 = 5.0840$ GHz

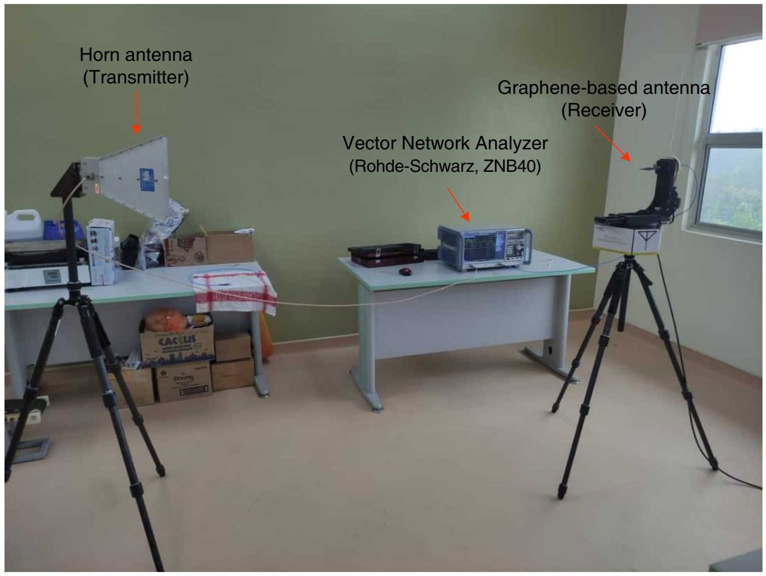


Figure 6. Measurement setup for radiation pattern.

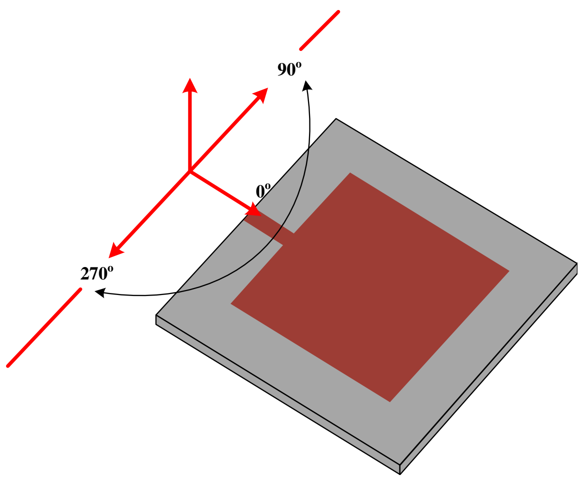


Figure 7. Antenna position for receiving antenna in radiation pattern measurement.

5.3. Radiation Pattern

The visual illustration of an antenna and the power it radiates in a certain direction is called a radiation pattern, formed between the antenna location and radiated power [14]. The antenna's radiation pattern is a representation of the energy it emits. In the radiation pattern measurement, a broadband horn antenna LB-880-NF with a gain of 10 dBi has been used as a transmitter. The antenna under test as the receiver is placed at 1 meter from the transmitter (LB-880-NF) as shown in Figure 6. The transmitter and receiver are respectively connected to port-1 and port-2 of the Rohde-Schwarz, ZNB40 vector network analyzer via coaxial cables. The output power at port-1 is fixed at 0 dBm at operating frequency of 5 GHz.

The position of the transmitter is fixed, and only the position (angle) of the receiving antenna is required to be changed or rotated as shown in Figure 7. The measurement was performed to acquire the rear lobe of radiation pattern for fabricated patch antenna. The corresponding measured receiving power for antenna was recorded and plotted by switching the position of the antenna. The measurement data have been normalized in order to be compared to the simulation data acquired by the HFSS software.

Figure 8 shows the comparison result of radiation pattern between simulation and measurement for patch antenna. It can be clearly seen that the measurement results are almost closed to the simulation result. The highest signal strength that the graphene-based patch antenna can collect is shown in Figure 8 to be 0 dB, and it is positioned at an angle of 345°.

Figure 9 shows the simulation result for patch antenna depicted from HFSS software. Figures 9(a) and 9(b) show the 3D radiation pattern and electric field distribution of patch antenna, respectively. It is apparent that the antenna with the strongest signal strength was positioned at 30° and 330°.

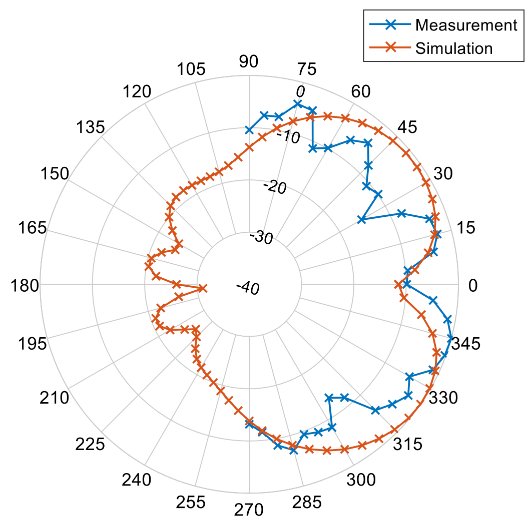
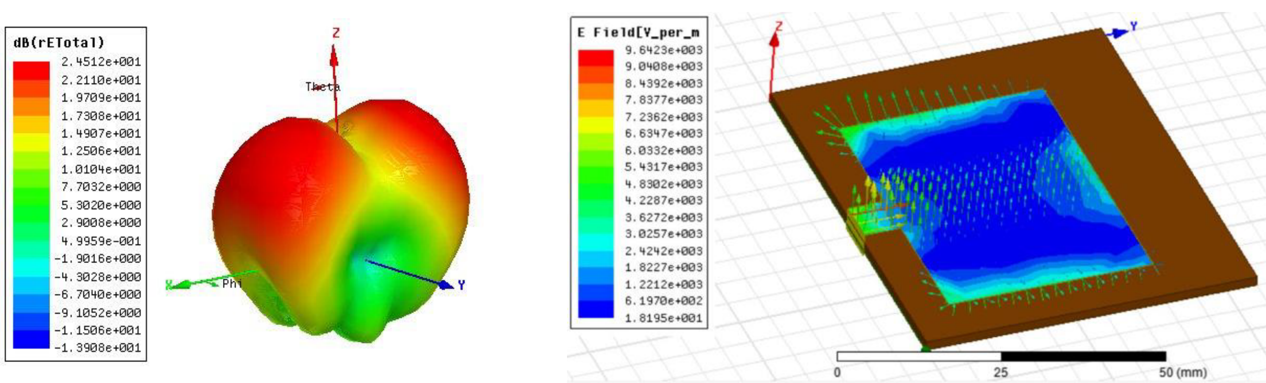


Figure 8. Simulation and measurement result of 2D radiation pattern for patch antenna.



(a) (b)

Figure 9. Simulation result of patch antenna, (a) 3D radiation pattern, (b) electric fields distribution.

5.4. Adhesion Test Result

As can be seen in Figure 10, an adhesion test was carried out using the scotch tape method in order to validate the adherence between the graphene paste and the substrate. After being peeled off from the graphene patch circuit, the Scotch tape appeared completely free of any particles, as revealed by the observation for the adhesion test. It was demonstrated that a high adhesion between the graphene paste and the substrate showed that the circuit had been properly prepared.

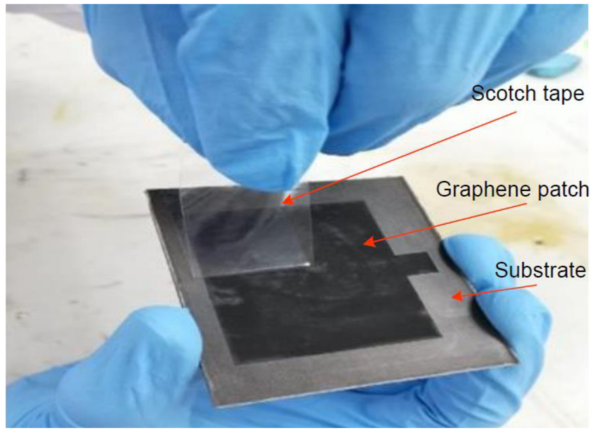


Figure 10. Adhesion test of fabricated graphene-based patch antenna using scotch tape.

6. CONCLUSION

This paper describes the fabrication of a graphene-based microstrip patch antenna with a resonant frequency of 5 GHz, return loss of −17.6314 dB, and bandwidth of 297.4 MHz. The fabricated antenna was compared with simulated one, and the results show a good agreement between simulated and fabricated antennas.

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