**Design and Fabrication of Flexible Nanoantenna-Based Sensor Using Graphene-Coated Carbon Cloth**

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Carbon nanomaterials have attracted significant consideration and concern due to the unique chemical and physical properties. Recently, nanodiamonds, graphene, and carbon nanotubes are served as electrodes, hydrogen storage elements, and composite materials. In this work, a 5 GHz graphene nanoantenna that falls inside the very-small-aperture terminal (VSAT) C-band range has been fabricated. A graphene substrate with a thickness of $h = 0.5$ cm is formed which is then used for fabricating a graphene nanoantenna working at 5 GHz. To design and simulate the antenna, Analysis System (ANSYS) electromagnetic desktop software was used. Using the designed graphene antenna, the parameters such as voltage standing wave ratio, three-dimensional radiation pattern, and directivity were obtained. After designing of the antenna using ANSYS software, it was physically fabricated. The graphene was used as a dielectric, copper sheet acted as a patch over as well as ground. Finally, the design was tested using Vector Network Analyzer (Model: N9925A) and the transmission range was found as 5 GHz.

1. Introduction

Nanotechnology refers to scientific and technical domains in which nanoscale phenomena are utilized in the production, characterization, design, and application of nanomaterials, nanodevices, and systems. Nanotechnology has emerged as one of the most important and exciting frontier subjects in physics, chemistry, engineering, and biology in recent years. It has the potential to provide substantial breakthroughs in the near future, impacting the direction of technological growth in a variety of applications. Nanotechnology, in all of its forms, has the potential to make a tremendous impact on society. Nanotechnology goods are expected to have an environmental effect due to the dispersion and permanence.
of nanoparticles in the environment. Composite is created by fusing two or more materials with diverse chemical or physical properties [1]. In this, one must have dimensions less than 100 nm. Depending on their intended function, composites and nanocomposites can be made from a number of materials. Nanocomposites and nanocrystalline solids are solid materials composed of one or more dispersed phases that take the shape of microscopic particles.

Nanocomposites are nanoparticle-based materials. Inorganic and non-polymer-based nanocomposites are made up of materials without the use of polymeric compounds [2]. Polymer nanocomposites are reinforced polymers that contain a modest number of nanometric clay particles, typically less than 5%. These materials stand out for their increased fire resistance and thermal stability, as well as their enhanced barrier qualities and increased recyclability. A polymer nanocomposite is a composite composed of a polymer matrix and a nanomaterial [3]. Additional forms of conventional fibre reinforcement may be used, as with ordinary polymer composites. Graphene is the strongest known material, tougher than steel yet lighter than aluminium. Other remarkable aspects such as high electron mobility, heat conductivity, electrical conductivity (13 times better than copper), and impermeability and its surface area are observed [4]. One of the simplest and most successful ways to unlock graphene’s potential is to combine it with existing products. Graphene is a material with several distinct properties, such as strength, flexibility, lightness, and conductivity. Graphene-based composites will have an influence across several sectors, improving performance and expanding application options [5]. Graphene is a very versatile substance that may be mixed with other elements (including gases and metals) to create a variety of compounds with varying superior features. Researchers all around the globe are continually investigating and patenting graphene in order to understand more about its numerous features and potential uses, which include antennas.

At low concentrations, the polymer/graphite composites demonstrated strong heat conductivity and electrical conductivity. An antenna is a metallic structure that collects and/or transmits radio waves. Antenna varies in size and design, from little ones on your roof to massive ones that catch signals from satellites millions of kilometers away. Wearable and point-of-care devices, 5G technology, and communication devices are in need of flexible antennas. There is access to a wide range of design advancements, novel materials and material features, innovative production processes, and niche applications. The substrate’s dielectric characteristics, mechanical deformation tolerance, miniaturization susceptibility, and environmental durability are all taken into account. The antenna’s performance, such as radiation efficiency, is determined by the conductive substance used. The extraordinary progress made in the fabrication and functionalization of graphene materials has opened up new avenues for their use. Well-organized, stretchy, and economical microstrip patch antenna was constructed on “glossy paper” at 1.57 GHz on an inkjet printer using silver nanoparticle ink. At temperatures as high as 180°C, the conductivity was increased to promising levels of up to 2/cm. Inkjet printing vs. post-synthesis annealing and multilayer printing were used to evaluate the performance of silver nanoparticle ink [6]. On silicon dioxide, where thickness \( h = 3 \text{ nm} \), frequency-reconfigurable antipodal Vivaldi antenna (AVA) was built using graphene. It was assessed using finite integration technique by electromagnetic modelling programme computer modelling technology. This antenna exhibited multiband resonances due to the hexagonal form of graphene [7]. Similarly, by using nano-stencil lithography, configurable infrared plasmonic nanorod antenna arrays were created [8]. Finally, they demonstrated the utilization of a single metal deposition technique to construct plasmonic nanostructures of various forms on a range of substrates, including non-conducting substrates. Cross dipole nano-antenna was developed with dual resonant structure for application in fluorescence-based sensing [9]. Similarly, hydrogel-coated bowtie nanoantenna arrays were developed [10]. By incorporating self-assembled graphene sheets into a polypropylene 3D framework, a self-recoverable flexible broadband microwave absorber was created. It features a 62.73 GHz bandwidth and a 97% absorption rate [11].

Jeon et al. [12] used highly conductive graphene/polymer nanocomposite sheets in flexible radio-frequency antennas through chemical vapour deposition. Conductivity and permittivity of nanocomposites were analyzed with respect to temperature [13]. Polyvinylidene fluoride films were created with alternating multilayer structures based on graphene for electromagnetic interference (EMI) shielding [14]. Graphene-poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT: PSS) composite with dielectric permittivity of 2.3 was used as substrate in antenna at 2.4 GHz. Owing to flexibility, efficiency, low cost, and electric field-controllable features, graphene/polymer composites are presently being investigated [15]. Kirtania et al. [16] focused on the various material qualities that impact antenna performance.

Carbon-based materials have been used to improve the heat conductivity of different polymer matrices. These materials have good mechanical strength, great thermal conductivity, and a tailorable electrical setup. Graphite, particularly expanded graphite, is very important due to its wide availability and relative lightness [17, 18]. Proper integration of atomically thin carbon sheets enhances the physical characteristics of host polymers, even at extremely low loadings [19]. Preparation of graphene/polymer composite is a simple way to improve polymer performance and broaden their application possibilities [20]. Extremely flexible antenna was designed using stacked graphene multilayers with conductivity of 4.20×105 S/m and the same has been tested for several commercial applications [21, 22]. Similarly, flexible and highly conductive antenna was fabricated using high conductive graphene-assembled film with flexible, lightweight, high conductivity, and mechanical stability [23].

Micrometer-sized graphene-based antennas are projected to transmit terahertz-frequency electromagnetic waves [24]. Nano-dipole and patch antenna with the size of several hundred nanometers would be capable of
transmitting electromagnetic waves in the terahertz region [25, 26]. In general, to match the antenna requirements of 5G mobile communication, the antenna's resonance frequency is set at 3.5 GHz. The transmission line model approach is used to investigate the electromagnetic field parameters of the antenna.

2. Experimental

Here, graphite powder, cement (grade: OPC 53), and refined wheat flour were bought and utilized. In order to create a compact graphene substrate, a fine substrate out of graphite and refined flour was made. Because refined wheat flour is created from the endosperm of the wheat grain, a fine substrate is generated. Refined wheat flour is made by grounding wheat and bleaching it with benzoyl peroxide. The final material is obtained by combining the flour with alloxan. This technique softens the flour, resulting in a delicate graphene substrate when combined with graphite powder. 5 g of refined wheat flour and 20 g of graphite powder were combined to make a graphene substrate as shown in Figure 1. Because a more robust substrate is necessary, cement is employed in conjunction with graphite. As a result, combined 20 g of graphite with 10 g of cement is used to create a hard substrate as shown in Figure 2. Owing to the nature of limestone and clay, a hard substrate is formed.

Physical characteristics such as relative permittivity, relative permeability, Lande G factor, bulk conductivity, and mass density were measured after the material was formed and then incorporated into Ansys Electromagnetic Desktop for antenna design. High-frequency structure simulator (HFSS) is 3D electromagnetic simulation software for designing and simulating high-frequency devices. The highest frequency of the N9925A is 9 GHz. It incorporates the most comprehensive portable T/R vector network analyzer (VNA). Similarly, sub-miniature coaxial cable (SMA) connector is a coaxial cable connector that is sub-miniature in size. SMA connectors are widely utilized for radio-frequency (RF) communication between boards, and they are employed in various microwave components like filters, attenuators, mixers, and oscillators. A hexagonal-shaped threaded external connection interface that may be tightened with a wrench is included with the connectors.

3. Design and Fabrication of Graphene Nanoantenna

After measuring the physical properties of the material and incorporating it in Ansys Electromagnetic software, a circular patch antenna is designed as shown in Figure 3. As the formed substrate is delicate, we covered it with carbon cloth as shown in Figure 4 so that it will not lose its conductivity as both have the same characteristics. Then, copper is used as a
circular patch over the dielectric substrate and a copper plate is used as ground. Now the physical properties are incorporated into ANSYS and the circular patch antenna is designed. Finally for fabrication, we have connected SMA connector connecting the patch, dielectric substrate, and ground and recorded the results using network analyzer as shown in Figure 5.

4. Results and Discussion

The resonant frequency is the frequency at which maximum power is provided to the patch, i.e., when the feed line and patch have the best impedance matching. It is also the point at which inductive reactance equals capacitive reactance and the impedance becomes totally resistive. The resonant frequency of the designed antenna is 5.77 GHz.

From Figure 6, it is recorded that the antenna has an upper cutoff frequency of 7.5 GHz and a lower cutoff frequency of 4 GHz. Therefore, the bandwidth of designed antenna is 3.5 GHz. From Figure 7, voltage standing wave ratio (VSWR) is 4.5 dB.

Directivity is the concentration of an antenna’s radiation pattern in a certain direction. The greater the directivity, the more focused or concentrated the beam of the antenna. If the directivity is higher, the beam will go further. Figure 8 shows a 3D plot of the planned antenna’s directivity.
Antenna gain refers to an antenna’s capacity to emit in comparison with a theoretical antenna. If an antenna could be designed to be perfectly spherical, it would radiate equally in all directions. Figure 9 shows the 3D plot gain of the proposed circular patch antenna.

One of the fundamental aspects of an antenna is its radiation pattern, which represents how the antenna distributes its energy in space. It is frequently made up of several lobes and is distance independent when measured far away from the antenna. When the EH plane is selected, the far field radiation sphere setup values of phi begin at 0 and end at 90, with a step size of 90. Similarly, with a step size of one, theta values start at -180 and conclude at 180. The simulation results reveal that the values of phi and theta are acceptable, as shown in radiation pattern 1. In actuality, a microstrip patch antenna radiates regularly to its patch surface. The antenna’s transmission patterns are omnidirectional, which means it can be used for wireless local area network (WLAN). It is compatible with 802.11a, which uses the 5.8 GHz frequency band to deliver wireless spread spectrum radio waves. Figures 10 and 11 show the radiation pattern of the constructed
5.77 GHz antenna. Resonant frequency is that frequency where maximum power is delivered to the patch.

The resonant frequency recorded from N9952A network analyzer for the designed antenna is 5 GHz. By calculating the difference of frequency between two marker points, the bandwidth of the designed antenna can be identified, and the difference of frequency between two marker points, the bandwidth is 4 GHz.

5. Conclusion

In this work, graphene is coated on carbon cloth and dried and the thickness of the substrate is measured. The fabricated circular microstrip antenna was tested and analyzed with a frequency of 1.5 GHz and the same has been simulated using the ANSYS HFSS software. The frequency response of the antenna is 5.77 GHz, and the bandwidth is 3.5 GHz. The VSWR of the designed circular patch antenna is 4.5 GHz. Also, the radiation pattern, directivity, and 3D gain plot were also recorded. Finally, after fabricating the circular patch antenna, a resonance frequency of 5 GHz is recorded in N9952A network analyzer and the resonant frequency is verified.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

References


