Graphene Based Voltage Controlled Frequency Reconfigurable Antennas

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***Abstract*— Graphene based frequency reconfigurable antennas with different configurations are compared. Each antenna is composed of an inset-fed rectangular patch connected to one, two or three shorted stubs via graphene nanoplatelets. The reactance at the radiating edge of the patch is varied by varying the graphene resistance inducing a shift in the resonant frequency. The graphene resistance is varied by applying a DC voltage between the feed line and the ground plane. Increasing the number of stubs increases the variation of reactance causing an increase of the frequency shift. The designs are validated by simulations and measurements. For the antenna with two stubs there is a frequency shift of 300 MHz while no significant impact of the stubs is noticed on the radiation pattern of the antennas.**

Keywords*— Graphene, tunable microwave devices, frequency reconfigurable antennas, voltage-controlled antennas.

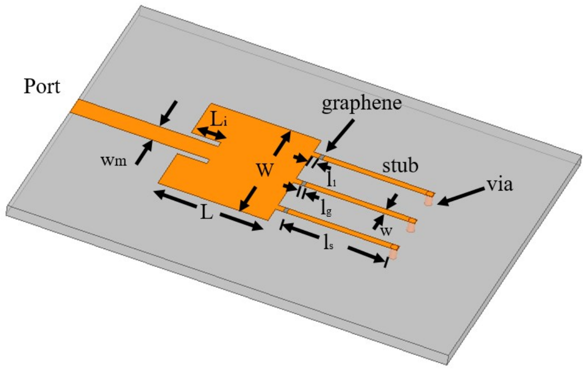


Fig 1. Geometrical representation of the graphene antenna.

I. Introduction

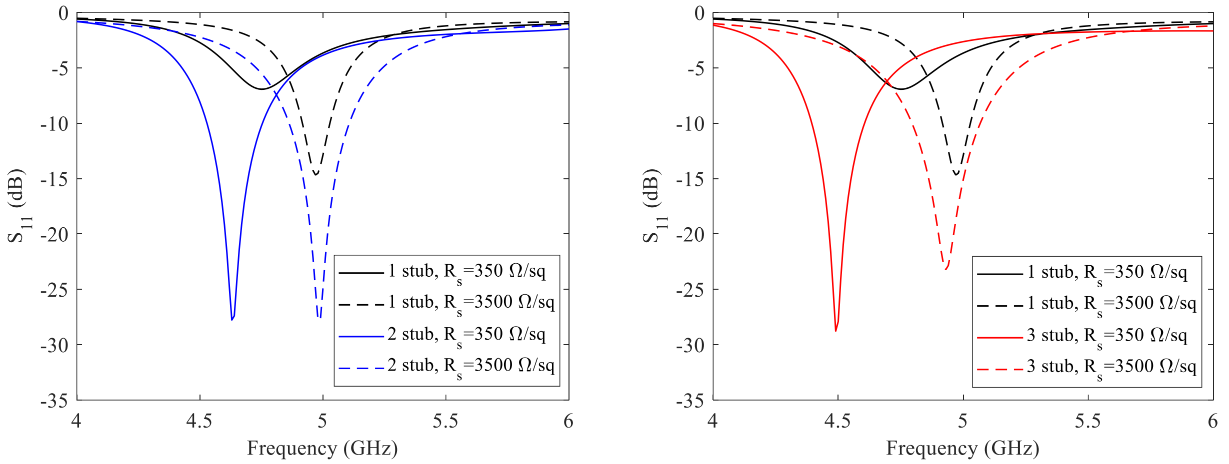
In recent years, carbon and its derivative materials have proven to be an emerging alternative for conventional materials due to their excellent electronic, mechanical and thermal characteristics. These unique set of characteristics grants carbon based materials a wide range of applications [1]-[2]. Graphene is par excellence the most noticeable of carbon materials for components and devices at frequencies ranging from DC up to terahertz (e.g. [3]-[5]) and beyond.

Graphene has been used in various forms e.g., films [6], composites, and drop casting. One of the most interesting properties of graphene is its tunable conductivity at a very large bandwidth. A bandwidth that covers the microwaves and millimeter waves range [2]. A number of innovative components have been designed exploiting graphene's tunable conductivity at the microwaves frequency band including attenuators [7]-[9], , phase shifters [10], antennas [11]-[14] and sensors [15].

For ease of fabrication and cost, the use of multi layered graphene is gaining traction in innovative components since just like single layer graphene it also possesses the tunable conductive behavior. The use of commercial graphene takes this ease of fabrication of innovative components based on graphene, one step further [9],[14].

Modern communication systems deploy a number of components working at a range of different frequencies, Communication between components working at different frequencies require the use of inter-connecting devices to tune their frequency remotely. Therefore, the use of frequency reconfigurable antennas is pivotal to their efficient functionality. The use of voltage controlled frequency reconfigurability is also important in places where the antenna itself is not physically accessible and therefore its frequency cannot be manually tuned. These can be remote places like forests or places that are hazardous for human beings e.g. places with very high temperatures like bushfire areas. By just changing the applied bias that can be supplied to the antenna along the feed lines, its resonant frequency is tuned. Conventionally, the frequency reconfigurability is performed by varying the capacitance at the radiating edge of a patch antenna by PIN diodes. Graphene along with a transmission line structure can be used to mimic the functionality of the PIN diode. The benefit of using graphene is its scalability retaining the tunable resistance properties and its functionality over a very wide band. Frequency reconfigurable antenna based on graphene has been produced on the principle of variable reactance at the radiating edge of a planar antenna [14].

In this paper, a comparison of tunable graphene antennas with different number of stubs is performed through simulations and measurements. The operating principle of graphene based frequency reconfigurable antennas is the variation of the resonant frequency by varying reactance at the radiating edge of a patch. The reactance variation is caused by resistance variation of graphene through an applied DC voltage. The lengths and widths of the stubs are optimized to maximize the reactance variation and the resulting variation of the resonant frequency. The impact of the stubs on the radiation pattern is analyzed and it is shown that increasing number of width does not vary the radiation pattern of the antenna. Furthermore, the impact of the increased number of stubs on the peak gain is also discussed.



(a) *(b)*

Fig. 2. Comparison of the return loss of the frequency reconfigurable antennas: *(a)* one stub antenna compared to two stub antenna; *(b)* one stub antenna compared to three stub antenna.

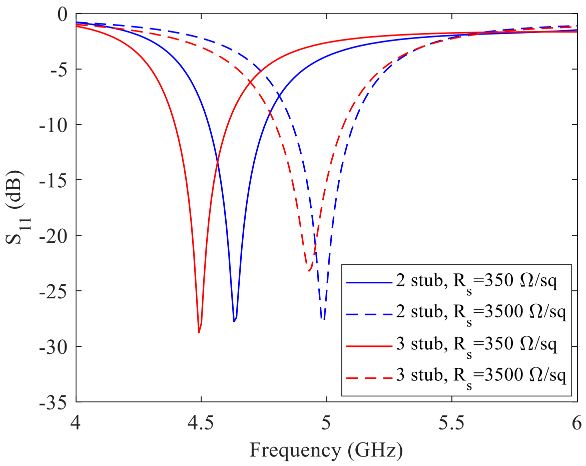


Fig. 3. Comparison of the return loss of the two stub antenna with the three stub antenna.

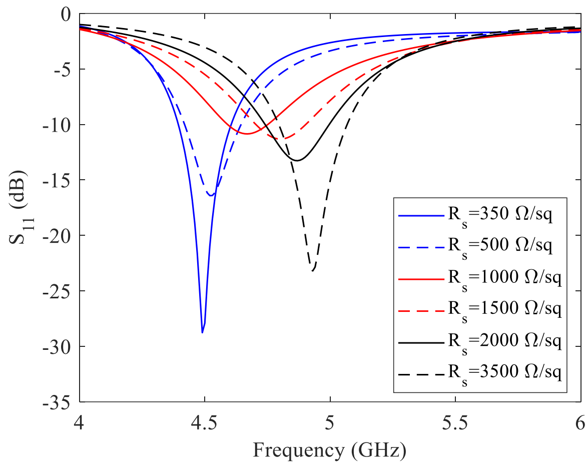


Fig. 4. Return loss of the reconfigurable antenna for a number of graphene resistance values.

II. DESIGN OF THE ANTENNAS

The phenomenon of frequency reconfigurable graphene antennas was investigated and optimized lengths and widths of stubs were acquired for a maximum reactance variation [14]. It was noticed that an increase in the number of stubs from one to two increases the reactance variation and the resulting shift in the resonant frequency of the patch antenna. A further increase in shift of the resonant frequency by increasing yet again the number of stubs from two to three needs to be investigated. The proposed antenna as shown in Fig. 1 is simulated by the help of an electromagnetic simulator, Ansys HFSS, where the graphene depositions are modelled as infinitely thin resistive sheets with assigned resistance in Ω/square.

The reconfigurable antenna is designed on a Rogers 4350B substrate having dielectric constant ε_r=3.66, loss tangent, tanδ=0.002 and thickness, h=1.52mm. It comprises of an inset fed patch of length, L = 25mm, width, W= 20 mm, the length of the inset is Li = 4mm and width is w_m=3.26mm corresponding to a characteristic impedance of 50 Ω. All the three stubs have identical dimensions. The widths of the stubs are w=1mm. The section connected to the patch is 1mm long. Graphene depositions have length, l_g=0.15mm and width, w_g=1mm. The length of the second section of each stub is l_s=15 mm. This section is shorted at the end with a metallic via having diameter d=1mm.

The antennas with one, two and three stubs are simulated for maximum and minimum value of graphene resistance of 3500 Ω/sq. and 350 Ω/sq. The return loss of the antenna with one and two stubs is shown in Fig. 2*(a)* and the return loss of the antenna with one and three stubs is shown in Fig. 2*(b)*. The antenna with two and three stubs shows great improvement in terms of the return loss as compared to the antenna with one stub.

A comparison of the return loss for the antenna with two and three stubs is shown in Fig. 3. For a maximum graphene resistance of 3500 Ω/sq., the two stub antenna resonates at 4.99 GHz with a return loss value of -27dB. For a minimum graphene resistance of 350 Ω/sq., the resonant frequency is lowered to 4.64 GHz with a return loss of -27dB. The antenna with three stubs resonates at 4.94 GHz for a maximum graphene resistance of 3500 Ω/sq. with a return loss of -23dB. The resonant frequency is shifted to

4.49GHz with a return loss of -28dB for a minimum graphene resistance of 350 Ω/sq.

The return loss is slightly improved in the case of the antenna with three stubs only for the minimum graphene resistance of 350 Ω/sq. For maximum graphene resistance of 3500 Ω/sq., it reduces to -23dB. The additional shift in resonant frequency and improvement of the return loss for minimum value of graphene can be attributed to a greater reactance variation caused by the additional stub drawing more current into the stubs. For higher values of graphene resistance this effect is negligible due to a very slight current drawn and the resulting slight variation in reactance.

The return loss for the antenna with three stubs for a number of different graphene resistances is shown in Fig. 4. The values of the return loss of the antenna gradually shifts from a maximum off 4.94 GHz to a minimum of 4.49GHz. At the maximum and minimum graphene resistance of 3500 Ω/sq. and 350 Ω/sq., the antenna shows good matching with reasonable matching at the intermediate values of graphene resistance.

III. Results

The commercial graphene nanoplatelets deployed in this work were provided by Nanoinnova. The nanoplatelets were characterized by FESEM (field emission scanning electron microscope) in order to observe the structure of the commercial graphene nanoplatelets by the

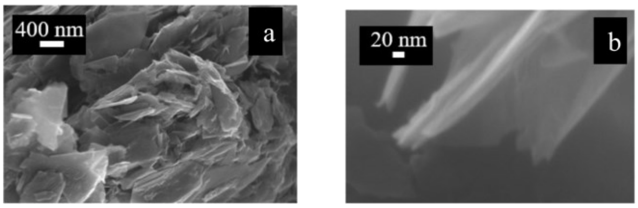


Fig. 5 FESEM images of the commercial graphene nanoplatelets.

help of ZIESS SUPRATM 40. Fig. 5 shows the FESEM images of graphene nanoplatelets. Individual graphene nanoplatelets can be seen in Fig.5a. where the thickness formed by a single nanoplatelets seem to be few nanometers. Transparency of an individual flake in Fig.5b. shows that the flake is composed of a few layers of graphene.

Prototype of the antenna with two stub was fabricated by the help of a standard etching procedure. Commercial graphene nanoplatelets were drop casted in the gaps between the stubs and the antenna. The measurement setup of the reconfigurable antenna is shown in Fig. 6 along with the fabricated prototype in the inset. To measure the return loss of the antenna with two stubs, the antenna is connected to a vector network analyzer (VNA). A broadband commercial bias-tee is connected between the VNA and the antenna feed line. Since the stubs are shorted to the ground plane at one end, therefore the voltage applied to the graphene flakes is between the ground plane and the feed line. The VNA is calibrated at the end on of the bias-tee in order to account for the effects of the bias-tee. The bias-tee is connected to a DC power supply at one of its ports. Values of DC current is measured for each value of the applied DC voltage. The values of graphene resistance can be calculated from the values of applied voltage and current drawn as shown in Table I. As expected, the resistance of graphene is lowered by increasing the applied DC voltage.

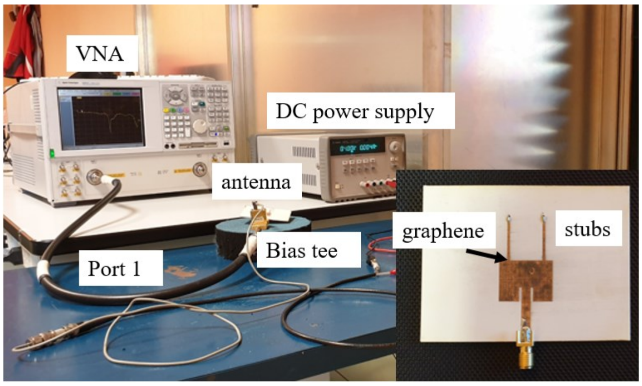


Fig. 6. Measurement of return loss of the reconfigurable antenna, with fabricated prototype in the inset.

The return loss values for each value of applied DC voltage is measured. Increasing the bias voltage the graphene resistance is lowered thus varying the reactance at the

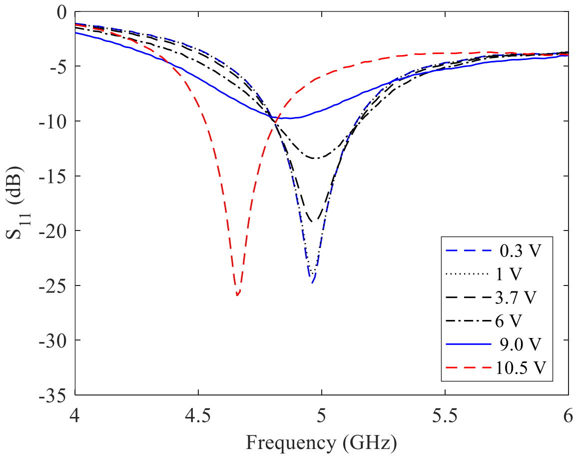


Fig. 7. Measured return loss of the reconfigurable antenna for different applied bias voltages.

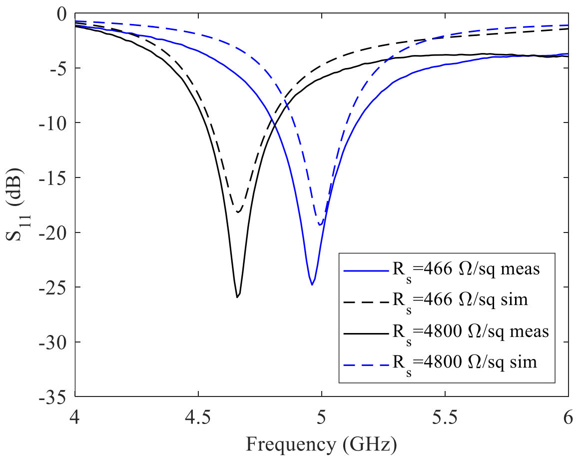


Fig. 8. Comparison of the simulated and measured return loss for the maximum and minimum graphene resistance.

radiating edge of the patch caused by the stubs. This tends to make the antenna resonate at a frequency lower than the design frequency. The values of the return loss for a range of different applied bias voltages is shown in Fig. 7. The resonant frequency of design is almost 5 GHz at an applied bias voltage of 0.3 V. Increasing the bias voltage to 10.5 V shifts the resonant frequency of the antenna to almost 4.7

GHz. For comparison of the measured and simulated return loss of the frequency reconfigurable antenna, simulations are performed for the maximum and minimum measured graphene resistance values.

TABLE I – VOLTAGE, CURRENT AND RESISTANCE VALUES OF THE TWO STUB GRAPHENE ANTENNA

Voltage (V)	Current (mA)	Resistance (Ω)	Sheet Resistance (Ω/sq.)
0.36	1	720	4800
3.7	25	298	1989
6.1	60	202	1355
9	140	120	800
10.5	300	70	466

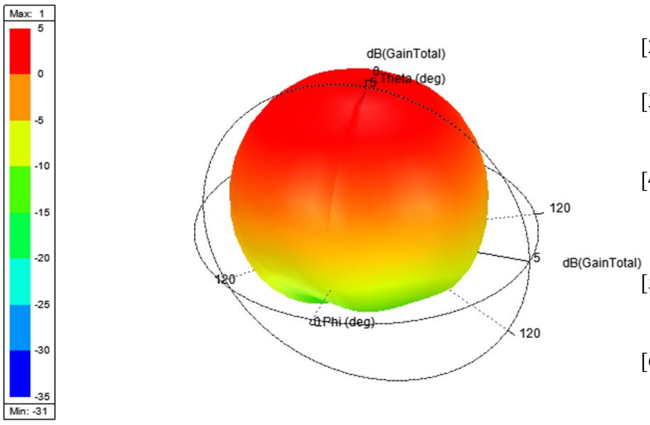


Fig. 9. Simulated gain of the antenna at the maximum graphene resistance of 3500 Ω/sq.

The return loss for the simulated and measured return loss at maximum and minimum graphene resistance is shown in Fig. 8. It can be seen that the simulated and measured return loss are in good agreement with each other. The measured return loss values are slightly lower than the simulated return loss.

Simulations were performed for the gain of the antenna at maximum and minimum graphene resistance. The gain of the antenna for high graphene resistance of 3500 Ω/sq. is shown in Fig. 9. The maximum gain in this case is 5 dBi. It can also be seen that there is no significant modification of the radiation pattern of the antenna due to the presence of the stubs. The radiation from the two stubs is non-existent in the radiation pattern of the antenna. The simulated gain for the minimum graphene resistance of 350 Ω/sq. is around 0.5 dBi. The reduction in the gain for minimum graphene resistance value can be due to an increased mismatch loss, which can also be seen in the return loss of the antenna.

IV. CONCLUSIONS

Several topologies of microstrip antennas with graphene depositions are compared. The antennas are designed for working at 5GHz. The resonant frequency can be tuned to a lower frequency by varying an applied DC voltage. Antennas with one, two and three stubs are simulated for maximum and minimum value of graphene resistance of 3500 Ω/sq. and 350 Ω/sq. The antenna with two stubs shows significant improvement in term of return loss as compared to the one stub antenna. The shift in frequency is also enhanced. The return loss of the antenna with three stubs is comparable in terms of magnitude to the two stub antenna with a slightly higher frequency shift.

There is no significant impact on the radiation pattern of the antenna due to the presence of the stubs. A reduction in the gain of the antenna is noticed for some graphene resistance values which can be due to the increased mismatch.

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