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Frequency reconfigurable antenna based on commercial graphene nanoplatelets

M. Yasir and P. Savi

A voltage controlled frequency reconfigurable antenna is presented. The reconfigurable antenna comprises of a microstrip patch antenna connected to two grounded stubs via commercial graphene nanoplatelets. An applied bias voltage varies the resistance of graphene. The lengths and widths of the stubs are optimized to cause a change in reactance because of a change in graphene resistance. A change in the reactance at the radiating edge of the patch antenna varies its resonant frequency. Commercial graphene nanoplatelets bear higher sheet resistance. The complete structure is designed to provide maximum frequency shift with minimum mismatch. The optimized simulated design is fabricated and comparable measured results are obtained. The resulting measured frequency shift is 310 MHz at a frequency of 5GHz.

Introduction: Carbon based materials have gained particular interest in recent years since they possess excellent electronic, mechanical and thermal properties [1]-[3]. Many applications based on their excellent properties have been proposed (see e.g. [4],[5]). Graphene is the most notable among carbon-based materials and it has been profoundly studied. Graphene has many applications in active devices [6] as well as sensing [7]. One of the most important properties of graphene is its tunable conductivity. Various applications exploiting the tunable conductivity of graphene have been proposed [8],[9].

The electron mobility of graphene is varied by a DC voltage causing a change in its electrical conductivity [10],[11]. The variation of the electrical conductivity is valid over a large frequency band from DC up to millimeter waves. It makes graphene suitable for a wide range of different applications including attenuators [12]-[14], phase shifters [15] and antennas [16].

The ease of fabrication of graphene is highly enhanced by using multilayered graphene instead of its mono-layered counterpart since the fabrication of monolayer graphene requires higher technological complexity. Furthermore, components working at lower frequencies are large and thus require larger quantities of graphene, therefore the provision of multilayered commercial graphene is crucial to their fabrication. The electrical conductivity of multilayered graphene just like monolayer graphene can be tuned by the help of a DC bias voltage.

Several tunable passive microwave components were designed based on lab grown multilayered graphene [12]-[16]. In order to facilitate fabrication of components on a large scale, commercial graphene nanoplatelets based tunable components needs to be fabricated and comparable performance should be ensured. One of the first attempts in designing a microwave tunable attenuator based on commercial graphene nanoplatelets was made in [17].

In this paper, a reconfigurable antenna is proposed. The proposed antenna is based on commercial graphene nanoplatelets. As demonstrated in [17], commercial graphene bear higher sheet resistance than lab grown graphene nanoplatelets and the tuning capability is limited. The antenna presented in [16] is redesigned with two stubs to cope for the limited tenability of commercial graphene nanoplatelets.

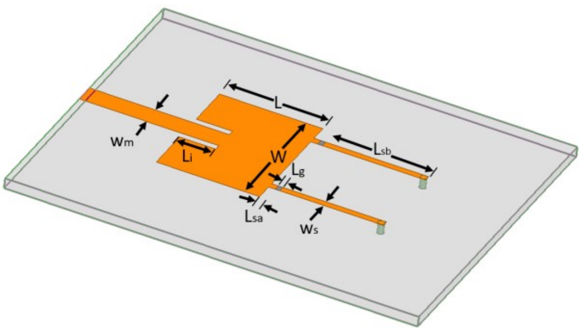

Fig. 1 *Geometry of the reconfigurable graphene antenna.*

The new design provides minimum reflection coefficient and a reasonable frequency shift. The operating principle of the antenna is based on the variation of sheet resistance of graphene by the application of a DC voltage. The variable resistance causes a variation of reactance caused by two stubs connected to the radiating edge of the patch antenna. This causes a shift in the radiation frequency of the patch antenna. The antenna was designed with the help of a commercial solver and a prototype was fabricated and measured.

Design: The reconfigurable antenna is composed of an inset fed patch antenna connected to two stubs via graphene nanoplatelets as shown in Fig. 1. The lengths of the stubs are optimized to vary their input reactance when the graphene resistance is varied. This is in principle similar to conventional method of using varactor diodes in tunable patch antennas [18]

The reconfigurable antenna design was simulated by the help of the commercial finite element method solver, Ansys HFSS. The commercial graphene nanoplatelets were modelled as resistive sheets with assigned resistance value in Ω/sq in the range of the measured graphene resistance values. The values of sheet resistance of commercial graphene nanoplatelets are too high to effectively modify the radiation frequency therefore the aspect ratio of the gap is reduced to modify the graphene resistance to a desirable value.

The substrate used for the design of the reconfigurable antenna is the Rogers 4350B. The dielectric constant of the substrate is εr=3.66 and loss tangent, tan δ = 0.002. The thickness of the dielectric substrate is h=1.52 mm and the feed line width amounts to wm=3.26 mm which corresponds to a characteristic impedance of 50 Ω. The patch antenna is inset fed with length of the inset, Li=4 mm. The width of the patch antenna is W=20 mm and length is L=25 mm. The section of the stub next to the edge of the patch is of length, Lsa=1 mm. The width of the stub is ws= 1mm. the gap with graphene depositions has length, Lg=0.15 mm, the length of the second section of the stub is Lsb=15 mm shorted by a grounded via.

An estimated value of the minimum and maximum sheet resistance of commercial graphene nanoplatelets is in the range of 3500 Ω/sq. to 350 Ω/sq. These sheet resistance of graphene can be converted to resistance by R=Rs AR, where Rs is the sheet resistance of graphene in Ω/sq., AR is the aspect ratio of the gap with graphene nanoplatelets is given by AR=Lg/ws The length Lg is kept low to reduce the resistance, R. The additional stub induces a higher variation of reactance and a resultant greater shift in the radiation frequency of the antenna. A comparison of the shift in radiation frequency with one and two stubs for the minimum and maximum graphene sheet resistance is shown in Fig. 2. It can be seen that the design with two stubs provide a return loss with higher matching and greater shift in frequency. The reflection coefficient is less than -25 dB with a frequency shift of almost 340 MHz for the two-stub design compared to a reflection coefficient of -15 dB with 230 MHz of the one stub design.

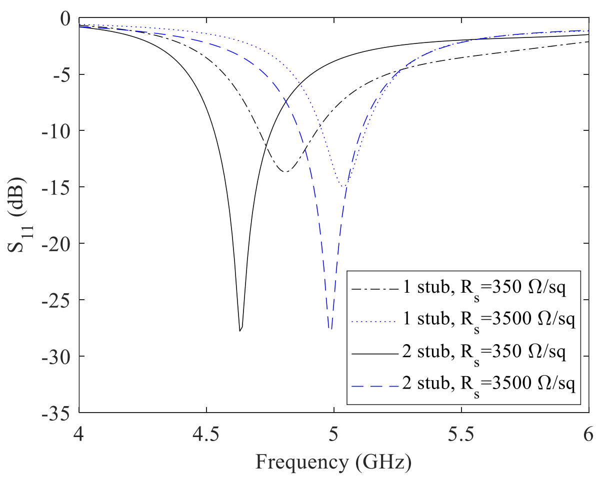

Fig. 2 *Comparison of the topologies of reconfigurable antenna with one stub and two stubs.*

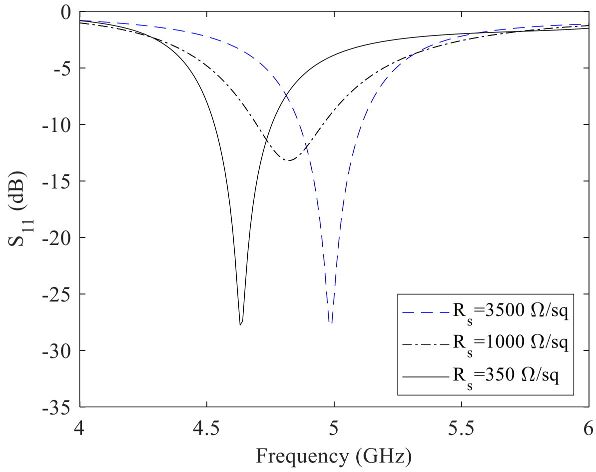

Fig. 3 *Simulated reflection coefficient of the reconfigurable antenna with different graphene sheet resistance.*

The simulated reflection coefficient of the antenna for estimated values of graphene sheet resistance is shown in Fig. 3. The variation in the radiation frequency is almost 330 MHz. At a sheet resistance of graphene of 3500 Ω/sq., the antenna resonates at the frequency of almost 4.99 GHz. As the graphene sheet resistance is lowered to 350 Ω/sq., a higher reactance at the radiating edge of the patch antenna shifts the resonant frequency to a lower value of 4.66 GHz.

Measured Results: The commercial graphene nanoplatelets deployed in this work were provided by Nanoinnova and were characterized in [17].

A prototype of the reconfigurable antenna (see Fig. 4 inset) was fabricated by the help of standard etching procedure. Commercial graphene nanoplatelets were mixed in isopropyl alcohol and then drop casted in the gaps on the stub along the lines. The sheet resistance of graphene is lowered by the help of an external DC bias voltage supplied between the ground plane and the antenna. The stubs are grounded at one end thus ensuring the electrical connection of the graphene to the ground plane.

The measurement setup of the reconfigurable antenna consists of a vector network analyzer, bias-tees, DC voltage supply and a reference antenna. The antenna under test is connected to one of the ports while the reference antenna is connected to the other port. The antennas are kept in line of sight and simultaneous measurements of DC and RF are carried out in an anechoic chamber. For each applied DC voltage, the scattering parameters are measured along with the current drawn. From the ratio of the current drawn and the voltage applied, the DC resistance is calculated by R=V/(2I) for each of the resistances, since they are in parallel. The corresponding sheet resistance is then calculated by Rs=R ws/Lg. Table 1 reports the DC values of the supply voltage, current drawn, resistance and sheet resistance. As the DC voltage increases, the sheet resistance of graphene is lowered. The varying reactance of the stubs at the radiating edge of the patch varies its resonant frequency. From the measured value of transmission scattering, and the value of the standard antenna gain, the test antenna gain is calculated by the substitution method [19].

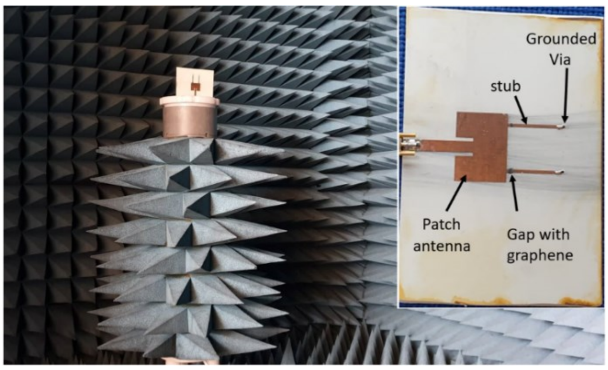

Fig. 4 *Measurements of the reconfigurable antenna in anechoic chamber (inset shows prototype with graphene).*

Table 1: Values of current, resistance and sheet resistance for respective applied bias voltage.

Applied Voltage (V)	Current drawn (mA)	Resistance (Ω)	Sheet Resistance (Ω /sq)
0.3	1	720	4800
9	140	120	800
10.5	300	70	466

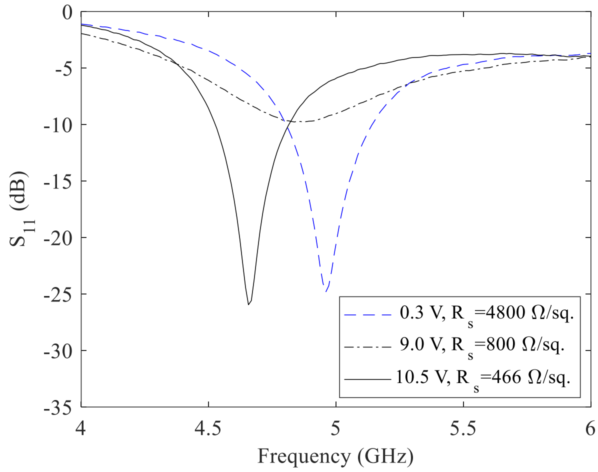

Fig. 5 *Variation of the measured reflection loss with different applied bias voltages.*

Table 2: Measured and simulated gain values at different applied bias voltage.

Simulated			Measured		
Sheet Resistance (Ω/sq)	Frequency (GHz)	Gain (dB)	Applied Voltage (V)	Frequency (GHz)	Gain (dB)
4800	4.99	1.9	0.3	4.96	1.6
800	4.80	0.6	9	4.89	-0.9
466	4.66	0.7	10.5	4.65	-0.1

The reflection coefficient, S_{11} for different values of applied voltages is shown in Fig. 5. A variation in the resonant frequency can be seen as the applied DC voltage increases from 0.3 V to 10.5 V. The reflection coefficient for the maximum and minimum applied voltage is less than -20 dB. The behavior of the reflection coefficient of the measured results is similar to the behavior predicted by the simulations of Fig. 3. Note that the measured reflection coefficients are slightly different from the simulated results because of the different values of the measured graphene resistance. At minimum applied voltage of 0.3 V, the antenna resonates at 4.96 GHz while at maximum applied voltage of 10.5 V the antenna resonates at 4.65 GHz. The total shift in the resonant frequency amounts to 310 MHz.

The values of sheet resistance obtained from the I-V measurements (see Table 1) are used as input for simulations. A comparison of the obtained values of the simulated and measured resonant frequency and gain is reported in Table 2.

Conclusion: A frequency reconfigurable patch antenna has been proposed in this letter. The antenna is composed of a patch connected to two grounded stubs via commercial graphene nanoplatelets deposited in designated gaps on the stubs. The lengths of the stubs are designed to maximize the variation of reactance on the radiating edge of the patch antenna. The sheet resistance of commercial graphene nanoplatelets is brought down to a desirable range by reducing the aspect ratio of the gaps. Upon the application of a DC voltage through the graphene nanoplatelets, their resistance reduces causing a variation in reactance along the edge. This causes a shift in the resonant frequency of the antenna. The shift in frequency is almost 310 MHz at the frequency of 5 GHz with a reflection coefficient of less than -20 dB.

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