Tunable Attenuator based on commercial graphene nanoplatelets

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***Abstract*— A series tunable graphene attenuator based on commercially acquired graphene nanoplatelets is presented. The attenuator is composed of a microstrip line with a gap. Graphene nanoplatelets are drop-casted in the gap. The transmission scattering parameters can be modified by a bias voltage supplied to the graphene nanoplatelets. Even though the resistance of commercially acquired graphene cannot be brought down beyond a specific value, yet the structure is designed to alter the resistance variation in a desirable range. The resulting dynamic range of transmission is comparable to a similar structure designed by lab grown graphene nanoplatelets. A prototype is fabricated and the simulated results are verified through experiments. The attenuator works from 1 GHz to 10 GHz with a maximum tunable range of up to 10 dB.**

***Keywords*— Graphene, tunable microwave devices, voltage-controlled attenuators.**

I. Introduction

The use of carbon based materials have got significant attention due to their superior electronic, mechanical and thermal properties. Their superior characteristics makes them suitable for use in a wide range of applications [1],[2]. Among nanomaterials, graphene is the most noteworthy because of its tunable conductivity among several other interesting electrical properties [3].

A change in the electron mobility of graphene through an applied DC voltage causes the variation of the conductivity of graphene. This variable conductivity is valid over a wide band of frequencies ranging from DC up to microwaves and millimeter waves [2]. Graphene in a number of different forms including films [4] has been used in a wide range of applications. In the form of flakes, it has been deployed in innovative components, structures and systems including antennas [5]-[7], phase shifters [8], sensors [9],[10] and attenuators [11]-[14].

The tunable conductive properties of graphene can be exploited in not only single layered graphene but also multilayered graphene consisting of less than 50 layers. Since the production of single layered graphene is costly and technologically complicated, it is highly desirable to use multilayered graphene for large-scale production of components. Lab grown graphene has been vastly used in the design of several versions of microwave attenuators [11]-[14]. With the availability of commercial multilayered graphene, the ease of production is further enhanced since its deposition requires very basic equipment.

Attenuators play a pivotal role in designing key components for microwaves transmission and reception systems. A first attempt to design a series tunable attenuator was made in [14] with limited functionality with regard to the variation of transmission loss.

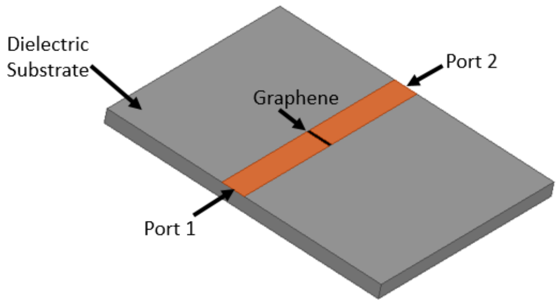


Fig 1. Geometrical representation of the graphene based series attenuator.

In this paper, a series graphene attenuator is proposed with superior functionality. The proposed design is composed of a microstrip transmission line with a gap in the middle where graphene is drop casted as shown in Fig. 1. The use of commercial graphene in the same structure as [14] does not provide similar performance since its resistance variation is limited by a higher minimum value. In order to achieve higher dynamic range of the transmission, a lower value of graphene resistance is required. The gap is redesigned with a smaller aspect ratio to lower the effective resistance.

II. Design of the Attenuator

The proposed design of the attenuator is composed of a microstrip line with a gap in between where the multilayered graphene nanoplatelets are deposited. Material characterization and detailed description of the graphene nanoplatelets were described in [15]. Increasing the bias voltage reduces the graphene resistance, which in turn increases the transmitted signal on the microstrip line.

The attenuator is first designed by the help of Ansys HFSS. Graphene nanoplatelets are modelled as resistive sheet with assigned sheet resistance in Ω/square in the range of the available graphene resistance. The attenuator is designed on the Rogers 4350B substrate (thickness h=0.786 mm, ε_r = 3.66 and loss tangent, tan δ = 0.004). The width of the microstrip line corresponding to 50 Ω is 1.66mm. The width of the gap with graphene is the same as that of the microstrip line while its length is 0.5mm kept as such to reduce the minimum graphene resistance.

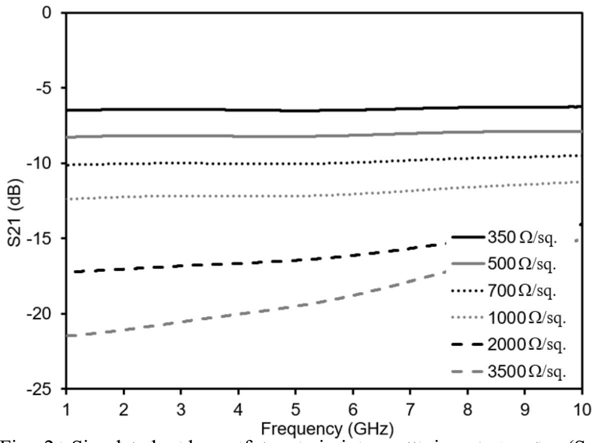


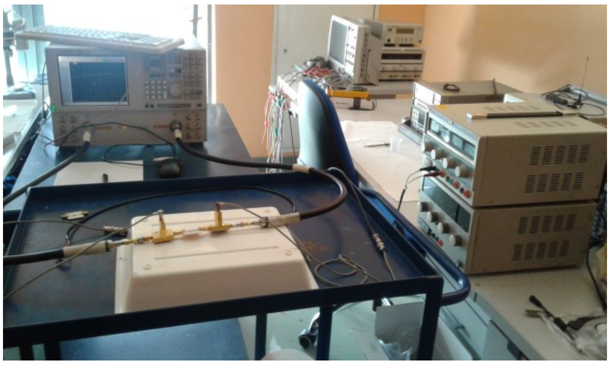
Fig. 2. Simulated values of transmission scattering parameter (S_{21}) for different values of graphene sheet resistance.

Simulations were performed with the described physical parameters for different values of graphene sheet resistance. As it was expected, the transmission varies with a variation in the graphene sheet resistance: a higher value resulting in lower transmission and vice versa. With a graphene sheet resistance of 3500 Ω/sq, the S21 is almost -21 dB increasing to almost -6 dB for a graphene resistance of 350 Ω/sq as shown in Fig. 2.

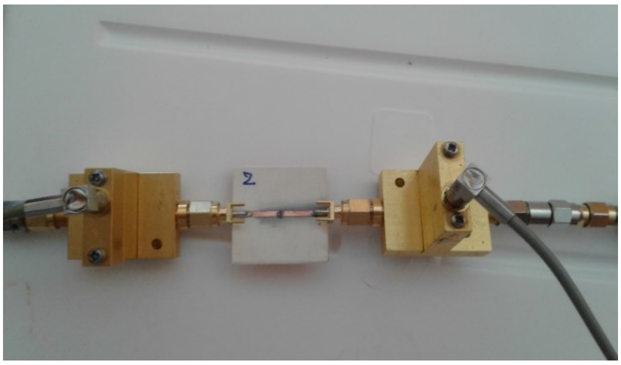
III. Measured Results

The prototypes were fabricated by applying photoresist on the two line sections and etching out copper from the remaining parts including the gap where graphene nanoplatelets were to be deposited. The graphene nanoplatelets used are commercially acquired and produced by Nanoinnova. The nanoplatelets are mixed in isopropyl alcohol and then drop casted in the gap. The gap is designed to bring the minimum value of the effective resistance down thus increasing the transmission for a maximum applied bias voltage.

The measurement setup is as shown in Fig. 3a. The two line sections are connected to a pair of bias tees, which are connected to the two ports of a vector network analyzer. Bias voltage from a variable DC power supply is applied which results in a variation of the graphene resistance. The applied bias voltage along with the corresponding graphene resistance is shown in Table I. Simultaneously, the scattering parameters are measured and the variation of the transmission coefficient is analyzed. The transmission for different applied bias voltage is shown in Fig. 4. The corresponding graphene resistance values can be related through Table I. The sheet resistance, Rs measured in Ω/sq. can be related to the measured resistance through $R=R_s\,L/W$ where L and W are the length and width of the gap, respectively. In our design L/W=0.32. The measured values of S_{21} for different values of graphene sheet resistance are comparable to the simulated results. The minimum S_{21} for an applied bias voltage of 1V is around -18 dB while the maximum S_{21} for an applied bias voltage of 9.6 V is up to -8dB. The dynamic range of S_{21} reduces at higher frequencies for the simulated and measured values. The increased intensity in dynamic range variation for the measured results can be attributed to the change in dielectric properties of the substrate with frequency, which for the simulated values are considered constant.



(*a*)



(*b*)

Fig. 3. *(a)* Measurement setup with the prototype connected to VNA and bias-tees *(b)* Tunable attenuator with graphene drop casted on the gap.

Table I – Voltage, current and resistance values of the Tunable Graphene Attenuator

Voltage (V)	Current (mA)	Resistance (Ω)	Sheet Resistance (Ω/sq.)
1	1	1000	3320
4	5	800	2656
7.8	15	520	1726
8.4	20	420	1394
8.7	25	348	1155
9.3	30	310	1029
9.6	35	274	910

IV. Conclusions

A series graphene tunable attenuator composed of commercial graphene nanoplatelets deposited in a custom designed gap in the middle of a microstrip transmission line is proposed. The series attenuator comprises of two 50 Ω line sections connected through graphene nanoplatelets. Commercial graphene nanoplatelets, which are readily available and easily deposited but have a limited minimum resistance value, are deployed. In order to increase the maximum transmission, a low graphene resistance is sought, which is acquired through a reduced length of the gap. This results in an increased variation of the transmission scattering. The attenuator works in the frequency range of 1GHz to 10 GHz with a maximum tunable dynamic range of the transmission of 10 dB.

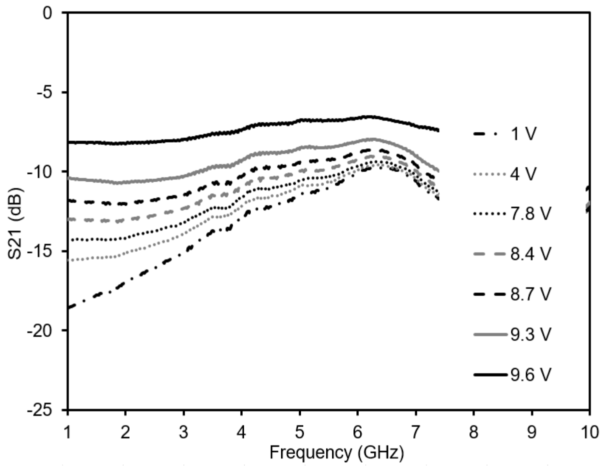


Fig. 4. Measured transmission scattering at different applied bias voltages.

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