Enhanced Tunable Microstrip Attenuator Based on Few Layer Graphene Flakes

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Enhanced Tunable Microstrip Attenuator Based on Few Layer Graphene Flakes

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***Abstract*—This paper presents a voltage-controlled tunable attenuator based on few layer graphene flakes. The proposed structure exploits the variation of graphene resistance with an applied bias voltage. The attenuator consists of a microstrip line, connected to grounded metal vias through graphene pads: when no bias voltage is applied, the resistance of graphene is high and the pads behave as open circuits, causing minimum attenuation. By increasing the bias voltage, the resistance of the graphene pads decreases, connecting the metal vias to the microstrip, thus increasing the attenuation. A prototype operating in the frequency band from DC to 5 GHz has been designed and tested. The measured attenuation ranges from 0.3 dB to 15 dB at 3 GHz, with a bias voltage ranging from 0 (minimum attenuation) to 6.5 V (maximum attenuation).**

***Index Terms*— Graphene, microstrip lines, tunable microwave devices, voltage-controlled attenuator.**

I. INTRODUCTION

THE USE OF GRAPHENE for microwave applications has been gaining wide interest in the past few years, thanks to its unique properties [1,2]. One of the most interesting features of graphene at microwave frequencies is the possibility to electronically modify its resistivity, which can vary over a large range of values [2].

Besides the single-layer graphene, the use of few layer graphene (FLG) appears particularly interesting, as it combines tunability features [3] with a much easier manufacturing process [4].

The tunability of FLG resistivity can be exploited in the implementation of wideband microwave attenuators, as proposed in [4]. The attenuator presented in [4] consists of a microstrip line with a gap, where a graphene pad is located: this corresponds to a variable resistor in series with the transmission line. Due to the achievable range of variation of the FLG resistivity, the attenuator in [4] exhibits an insertion loss ranging from 5 dB to 10 dB.

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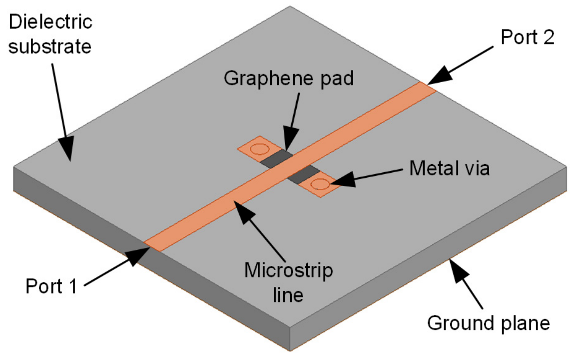

Fig 1. Geometry of the graphene-based tunable microstrip attenuator.

This paper proposes a novel attenuator topology to extend the range of tunability of the attenuator and to reduce the minimum value of insertion loss. In the proposed attenuator, the graphene pads are located between the microstrip line and a pair of grounded metal vias (Fig. 1). At zero bias voltage across graphene, the pads exhibit high resistance and behave almost as open circuits, thus ensuring an almost complete transmission of the signal from port 1 to port 2. Increasing the bias voltage across graphene reduces its resistance, hence allowing more current to pass through it. This, in turn, attenuates the signal traveling through the microstrip line. The design and fabrication of a tunable microstrip attenuator, based on FLG and operating in the frequency range from DC to 5 GHz, is presented in this paper, along with experimental results.

II. DESIGN OF THE TUNABLE ATTENUATOR

The proposed topology of the graphene-based tunable microstrip attenuator is shown in Fig. 1. The mirrored configuration and proposed size of the graphene patch ensures higher and more stable attenuation in the frequency band of operation.

The circuit was designed on CER-10 Taconic dielectric substrate with thickness h=1.27 mm, dielectric permittivity ε_r=10, and loss tangent $\tan\delta$=0.0035. The microstrip line width was set to 1.17 mm in order to get a 50-Ω line. The graphene pad has a length 1.40 mm and a width 0.66 mm, the metal via has a radius of 0.4 mm and the square metal patch on top of the via has a side of 1.4 mm.

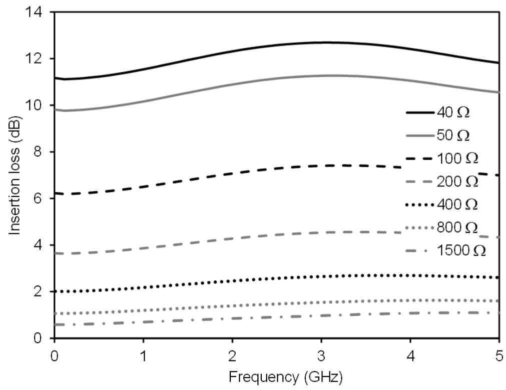

Fig. 2. Simulated scattering parameters of the attenuator for various values of the graphene resistance.

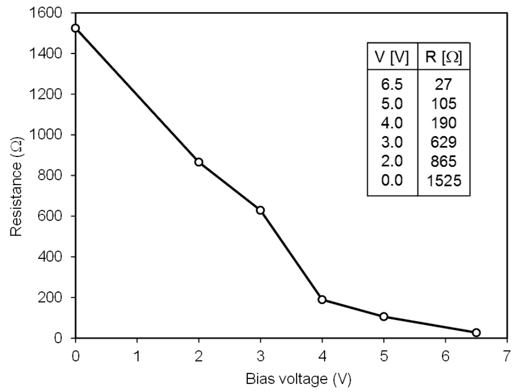

Fig. 4. Measured graphene resistance versus bias voltage.

The structure has been simulated in the frequency range from 0.01 GHz to 5 GHz using a commercial FEM solver, where the graphene pad is modeled as an infinitely thin resistive patch. The simulations were performed for a range of different values of resistivity, from 40 Ω/☐ to 1500 Ω/☐, according to the results in [4]. As expected, by decreasing the graphene resistivity, a higher value of insertion loss is achieved, as shown in Fig. 2: according to simulations, the minimum insertion loss is below 1 dB with a resistivity of 1500 Ω/☐, whereas the maximum insertion loss is larger than 12 dB, obtained with a resistivity of 40 Ω/☐.

III. PROTOTYPE AND EXPERIMENTAL VALIDATION

A prototype of the tunable microstrip attenuator was fabricated in order to verify its electromagnetic performance (inset of Fig. 3). The microstrip line and the vias were fabricated by using an LPKF micro-milling machine, and the vias were metalized by adopting conductive paste. The FLG was obtained by microwave exfoliation method [4]-[7].

The prototype was then tested using an Anritsu test fixture as shown in the Fig. 3. Commercial bias tees were used to bias the graphene pads. The bias voltage was applied between the microstrip line and the ground plane, since the graphene pads are grounded on one side through the vias.

In order to evaluate the resistance of the graphene for a given bias voltage V_{bias}, the current I_{dc} flowing through it was

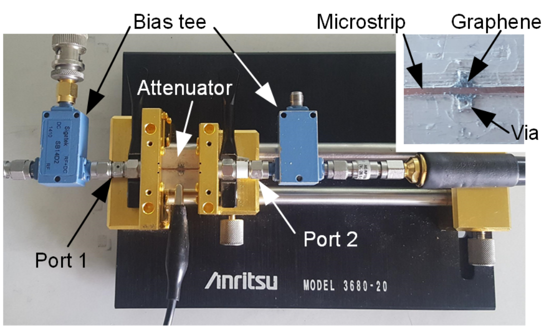

Fig. 3 Photograph of the measurement setup with the tunable microstrip attenuator (close-up of the prototype in the top right corner).

measured using a DC multimeter. The resistance R of the graphene pad can be computed from the value of the applied bias voltage and the current flowing through it (R=$V_{\mathrm{bias}}/I_{\mathrm{dc}}$). A plot of the graphene resistance versus the applied bias voltage is shown in Fig. 4. Increasing the bias voltage reduces the resistance of the graphene pad. The value of graphene resistance varies from 1525 Ω (with zero bias) to 27 Ω (with a bias voltage of 6.5 V). Exceeding the value of 6.5 V causes the breakdown of the circuit.

Simultaneously, the RF measurements were carried out in the frequency band from DC to 5 GHz by using a vector network analyzer for various values of bias voltage. To remove the effects of the bias-tees, the network analyzer was calibrated at the connectors of the test fixture (Fig. 3). Fig. 5 shows the insertion loss of the RF signal (traveling along the microstrip line from port 1 to port 2) at the frequency of 3 GHz versus the bias voltage. Individual contributions of dissipation and reflection to the attenuation are identified. As expected, the insertion loss increases with the bias voltage, from a minimum of 0.3 dB with zero bias to a maximum of 15 dB with a bias voltage of 6.5 V.

In order to compare simulation and measurement results, the relation between graphene resistance and bias voltage shown in the inset of Fig. 4 needs to be exploited. In this way, a plot of the measured insertion loss versus the graphene resistance is obtained and shown in Fig. 6, along with simulation results for the corresponding values of resistance.

Finally, Fig. 7 shows the performance of the tunable attenuator over the entire frequency band from DC to 5 GHz. In particular, Fig. 7*a* shows the measured results versus frequency, for different values of bias voltage, and Fig. 7*b* reports the simulation data computed for the resistance values corresponding to the set of voltages used in the measurements. It can be observed that the structure exhibits a stable wideband attenuation.

Table I shows a performance comparison of the tunable attenuator proposed in this work with structures presented in the literature. It can be noted that the proposed solution is outstanding in terms of tunability dynamics and exhibits a very limited minimum insertion loss (IL).

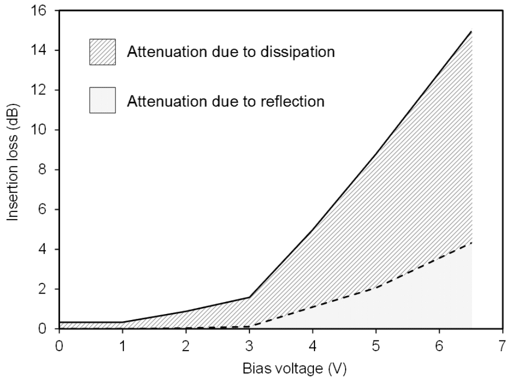

Fig. 5. Measurement of the insertion loss vs. bias voltage at the frequency of 3 GHz.

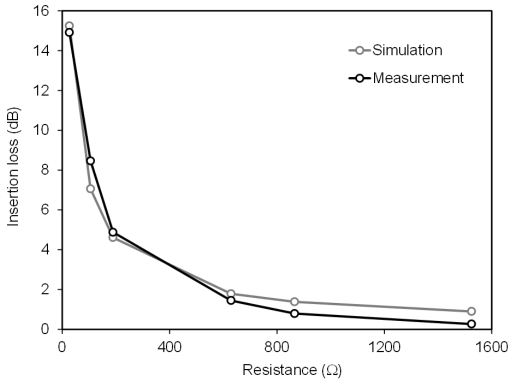

Fig. 6. Comparison of simulated and measured insertion loss vs. graphene resistance at the frequency of 3 GHz.

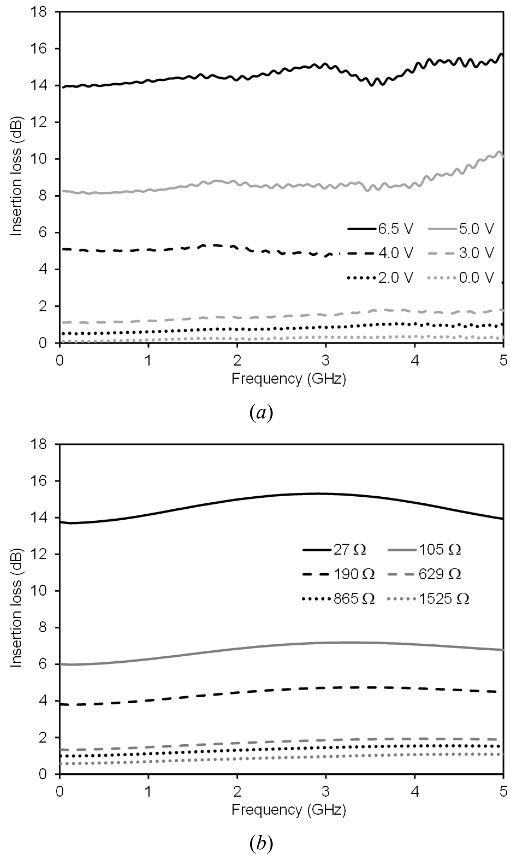

Fig. 7. Insertion loss vs. frequency: (*a*) measured results for different values of bias voltage; (*b*) simulation results for different values of graphene resistance (corresponding to the values of bias voltage adopted in the measurement).

IV. CONCLUSION

This paper presented an improved tunable microstrip attenuator based on few layer graphene flakes. The attenuator consists of a microstrip line and two grounded vias separated by a gap, where the graphene pads are located. An external bias voltage allows tuning the graphene resistance, in order to modify the insertion loss of the microstrip device from a minimum value of 0.3 dB to a maximum value of 15 dB at the frequency of 3 GHz. The attenuator exhibits quite uniform performance over the frequency band from DC to 5 GHz. Compared with the solution in [4], the proposed structure significantly extends the tunability dynamics and drastically reduces the minimum insertion loss.

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TABLE I
PERFORMANCE OF GRAPHENE-BASED TUNABLE ATTENUATORS

	Frequency (GHz)	Δ IL (dB)	min IL (dB)
[1]	3-7	4	4
[4]	1 - 20	2.5-5.5	2.9-9.3
This work	0-5	14.0-15.3	0.1-0.3

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