On Using Graphene-Based Conductors as Transmission Lines for Feed Networks in Printed Antenna Arrays

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***Abstract*—The use of graphene-based conductors (GBC) as a transmission line (TL) is presented as a conventional TL possessing right-handed (RH) nature and its coupling characteristics are investigated. In order to verify and demonstrate the wave propagation of a GBC TL, a 120 mm long 50 Ω TL was fabricated and tested. Performance of the single GBC TL was then compared to the conventional microstrip TL, analyzing the matching and wave propagation results. To investigate the unwanted coupling that may occur in a feed network, a similar GBC and a conventional microstrip TL, as well as two parallel GBC TLs on the same substrates were separately manufactured and tested to complete the study. It is shown that GBC TLs support the wave propagation in a fashion similar to the microstrip TL with an attenuation of less then 3.0 dB up to 7 GHz. Also the measurements of the near-end coupling showed that the two parallel GBC TLs have fairly good isolation in the frequency band of 4.5 KHz to 8.5 GHz, whereas the far-end coupling exhibits similar properties to that of the parallel microstrip TLs with same distance between them. The results demonstrated that GBC TLs could hence be a potential candidate for the feed network for planar antenna arrays.**

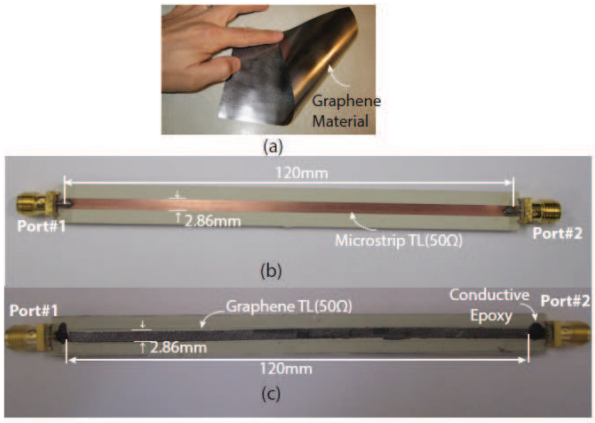

Fig. 1. (a) Commercially available graphene-based conducting material, (b) conventional microstrip transmission line (TL) and (c) graphene-based conductors (GBC) TL.

I. Introduction

Printed antennas are the promising candidates for microwave applications, where the emphasis is on reducing the volume and weight, especially when conformal antenna arrays are needed. These antenna arrays however show gain and efficiency limitations due to ohmic and dielectric losses in the feed network, caused by the unwanted coupling in the feed network and due to surface waves excitation in the dielectric substrate [1], [2]. This unwanted coupling in the TLs of long and complicated feed network has been a serious design issue as the efficiency limitations are most severe in large arrays due to high losses at high frequencies. As reported in [3], reducing the losses in the feed network of these antenna arrays significantly improve the gain and overall efficiency. Copper microstrip TLs have been the preferred choice when designing the feed network for antenna arrays but besides other drawbacks, they tend to fail and crack in conformal applications [4]. The demand for various new composite materials with structural strength and high electrical conductivity has hence been increasing to fill this gap. The graphene-based conducting (GBC) sheet is flexible and provides good electrical conductivity [5], therefore it is considered to be a good candidate for conformal applications. The use of GBC as an alternative to copper for antenna design on a conformal surface has initially been explored in [6].

In this paper, replacing the copper conductors with GBC sheets [7] as shown in Fig. 1(a) for TLs has been investigated. Also unwanted coupling between a conventional copper microstrip and a GBC TL, as well as two parallel GBC TLs manufactured on the same substrate has been studied and analyzed. The results show that the GBC TLs can be used as an alternative to copper TL with some limitations but are more flexible, light weight and give better results for unwanted coupling at high frequencies.

The paper is organized as follow: Section II describes the manufacturing of GBC TLs and explains the experimental setup. Next, the results of near- and far-end coupling are

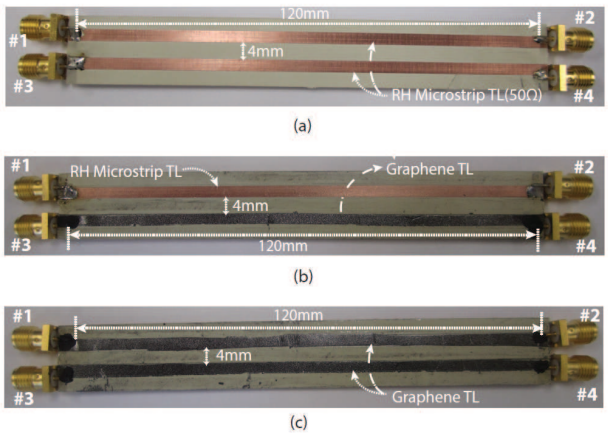

Fig. 2. Detailed pictures of (a) two 50Ω microstrip TLs, (b) a microstrip and a GBC TL, (c) and two GBC TLs.

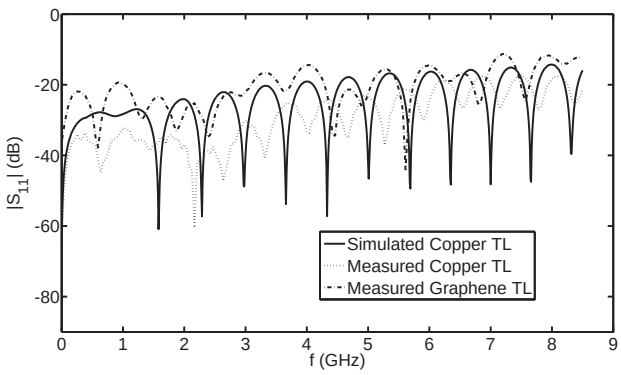

Fig. 3. Matching performance ($|S_{11}|$(dB)) of the microstrip and GBC TLs.

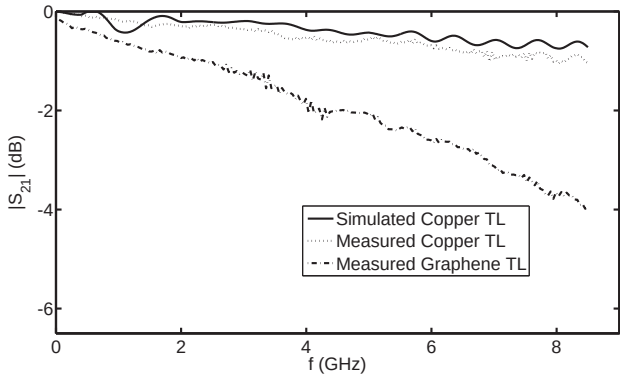

Fig. 4. Magnitude of forward transmission ($|S_{21}|$(dB)) of the microstrip and GBC TLs.

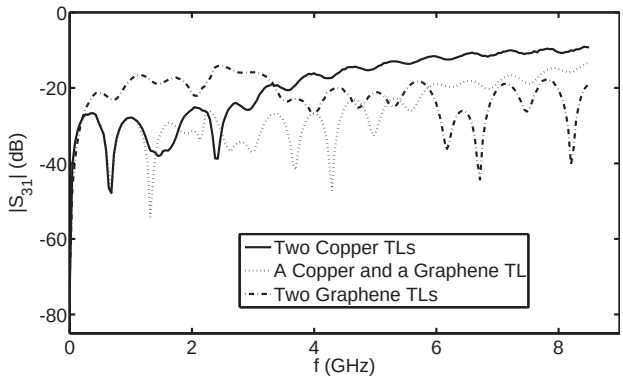

Fig. 5. Magnitude of near-end coupling ($|S_{31}|$(dB)) between the microstrip and GBC TLs.

presented in section III. Finally, section IV concludes the paper.

II. Prototypes of the Conventional Copper and Graphene-Based Conductors (GBC) Transmission Lines (TLs)

As illustrated in Fig. 1(b) and (c), two similar 50 Ω TLs (a conventional microstrip and a GBC) were first fabricated on TMM4 substrate (ε = 4.5, tan δ= 0.0020 and thickness, T_s = 1.52 mm) with copper ground plane on the bottom side. The S-parameters of the microstrip TL were first simulated using commercially available Keysight's Advanced Design System (ADS) [8] and later measured with a calibrated vector network analyzer, E5071C. Simulated and measured results agreed well with the simulations and served as a reference in designing the GBC TL. The manufacturing process of GBC TL was adapted from the method reported in [9]. A 2.86 mm wide and 120 mm long graphene sheet was first glued on the top surface of the substrate and then connected to the 50 Ω SMA connector using conductive epoxy.

For the comparison of unwanted coupling measurements, three prototypes as shown in Fig. 2(a), (b) and (c), were manufactured and tested. Similar geometries were used on the same substrate (with copper ground plane) for all the prototypes to investigate the unwanted coupling.

In order to measure the near-end coupling, port 2 and 4 were terminated with the 50 Ω load, while the other two ports (1 and 3) were connected with the network analyzer for measurements. Similarly, far-end coupling was measured by terminating the port 2 and 3, while measurements were taken at port 1 and 4.

III. Results and Discussion

Results of the matching performance and wave propagation of microstrip and GBC TLs are shown in Fig. 3 and Fig. 4, respectively. Comparing to the microstrip TL, it can be observed from Fig. 3 that the GBC TL also has a good matching performance up to 8.5 GHz. Fig. 4 shows the wave propagation of the simulated and measured microstrip TLs and also the measured GBC TL. As illustrated, -3 dB point of the GBC TL is at 7 GHz, which shows its limitations at high frequencies.

Fig. 5 shows the comparison of the simulated and measured near-end coupling between the two microstrips TLs, measured microstrip−GBC TLs as well as the two GBC TLs. It is observed that the two parallel GBC TLs have better isolation up to 8.5 GHz, which is much better than the two

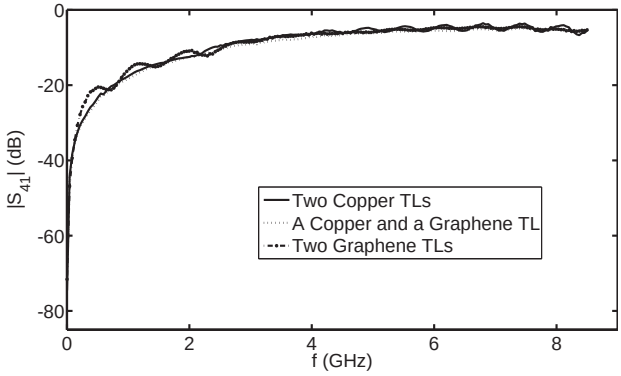

Fig. 6. Magnitude of $|S_{41}|$(dB) (near-end crosstalk) of microstrip and graphene TLs.

equally spaced conventional microstrip TLs and conventional microstrip−GBC TLs.

The far-end coupling in terms of $|S_{41}|$ (dB) for the prototypes is depicted in Fig. 6. This result shows that the far-end coupling does not exhibit any oscillations for the case of microstrip−microstrip TLs, microstrip−GBC TLs and the two parallel GBC TLs. For the case of two parallel microstrip TLs, the magnitude of the sine function never gets large enough to cause oscillations [10], this phenomenon may occur for two parallel GBC TLs too. It is hence argued that the microstrip−GBC TLs and the two parallel GBC TLs exhibit similar behavior to that of the two parallel microstrip TLs.

Very recently, carbon microfiber TLs were investigated for feed network in arrays [11] but it is observed that GBC TLs have better potential to be used as an alternative to the conventional TLs for conformal feed networks application. Finally, the DC resistances of the fabricated microstrip and GBC TLs, as shown in Fig.1 (b) and (c) have been measured using $GW\ Instek$-819 LCR meter and found to be 0.0471 Ω and 1.44 Ω, respectively.

IV. Conclusion

The impedance matching characteristics and the wave propagation of the GBC TLs have been demonstrated in this paper. Moreover, comparison of the near- and far-end coupling of the conventional microstrip TLs with the GBC TLs have been elaborated in detail. It is observed that GBC TLs have very good matching performance and also support wave propagation up to 7 GHz. Furthermore, the $|S_{31}|$ (dB) results showed that at higher frequencies, two parallel GBC TLs have better isolation than the conventional microstrip TLs. It is also concluded that GBC TL is less effected by unwanted coupling at high frequencies, even if it is located in close proximity of conventional microstrip TLs. The GBC TL is hence proposed as a novel alternative for many applications including the feed networks of the microstrip antenna arrays but the authors recommend to extend this work to test on conformal surfaces.

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