Wave Propagation and Coupling of Graphene-based Conductor Transmission Lines on a Conformal Surface - An Experimental Study

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Abstract—In this paper, the wave propagation of a graphene based conductor (GBC) transmission line (TL) and its comparison with a copper TL on a conformal surface is presented. An investigation of the coupling between parallel GBC TLs and copper TLs is also summarized in this work. A 150 mm long TL was initially manufactured on a flexible substrate and the wave propagation characteristics were investigated on a conformal surface. Then, a microstrip copper TL was manufactured and the wave propagation on a conformal surface was compared with the GBC TL. Also, prototypes with various combinations of two parallel TLs (GBC-GBC TLs, GBC TL - Copper TLs, etc.) were manufactured and studied for comparison. It was shown that the wave propagation properties of a given GBC TL on a conformal surface were similar to that of a copper TL over the frequency band of 100 KHz to 8.5 GHz. Moreover, results of the near- and far-end coupling showed that the GBC TLs can be used as an alternative to copper TLs as they can provide better coupling on a conformal surface.

I. INTRODUCTION

Research in antenna arrays for conformal applications, especially space-born applications has been increasing. However, in most conformal antenna array systems, mutual coupling between the feed array can not be neglected and must be reduced to improve the overall performance and efficiency [1], [2] of a conformal array. Traditionally, the feed network consists of copper transmission lines (TL), which are more vulnerable to failure and cracking in conformal antenna applications. Researchers have therefore been seeking interest in investigating composite materials with high conductivity, good structural strength, and good wave propagation properties. Recently, a graphene based conductor (GBC) sheet [3] has been used in antenna designs [4]- [5] and also studied as an alternative to conventional TLs for feed networks in planar antenna arrays [6]. As mentioned in [6], this work extends the research on the applications of GBC based conducting sheets.

More specifically, this paper presents a new investigation of the wave propagation properties and coupling characteristics of GBC TLs on a conformal surface. In particular, the GBC and copper TLs were manufactured using flexible substrates and the impedance matching, transmission properties, near-end, and far-end voltages were investigated on a Styrofoam sphere, as shown in Fig. 1. Moreover, a comparison analysis of matching and coupling characteristics for two parallel Copper TLs, GBC TL-Copper TL, and GBC-GBC TLs showed that the GBC TL can be used as an alternative to copper on conformal surfaces.

II. METHODOLOGY AND FABRICATION OF PROTOTYPES

The prototype transmission line (TL) structures were fabricated using a flexible 20 mil thick Rogers RT/duroid 6002 laminate (\(\varepsilon_r = 2.94, tan \delta = 0.0012\)) with 17.5 \(\mu\)m copper cladding on both sides. First, a 3 mm wide and 150 mm long single copper TL (\(Z_0 = 30 \Omega\)) was fabricated and used as a benchmark in this experiment. However, to fabricate the TL using graphene-based conductors [3], copper cladding was removed from the top layer using the LPKF milling machine and the procedure reported in [5] was adopted. The dimensions of the manufactured prototypes using the GBC are shown in Fig. 1. In particular, a 3 mm wide and 150 mm long GBC sheet was glued on the top of the given substrate and a 50 \(\Omega\) high frequency SMA end launch connector was attached using conductive epoxy.

For a comparison of coupling, three separate prototypes were studied. First, two parallel copper TLs, then two parallel GBC-TLs, and finally a copper TL in parallel with a GBC TL were manufactured with the same dimensions illustrated in Fig. 1 (a)-(b). All the measurements were performed by

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securing the prototypes on a Styrofoam sphere (radius = 20.32 cm), as shown in Fig. 2 (a)-(c).

III. RESULTS AND DISCUSSIONS

All the measurements of the manufactured prototypes were completed using a calibrated vector network analyzer (VNA), Keysight E5071C. A comparison of the $|S_{11}|$ and $|S_{21}|$ values for both the GBC and copper TLs are shown in Fig. 3. As observed, the GBC-TL has shown good impedance matching and similar wave propagation characteristics to the copper TL. It is mentioned that the GBC-TL is more vulnerable to cracking and has good mechanical strength as compared to copper TLs on a conformal surface.

In order to measure the near-end coupling, ports 2 and 4 were terminated with 50 $\Omega$, while the VNA was connected to ports 1 and 3. Similarly, the far-end coupling was measured by connecting the VNA to ports 1 and 4 and terminating ports 2 and 3 with 50 $\Omega$. The results of the near- and far-end coupling ($|S_{31}|$ and $|S_{41}|$) are shown in Figs. 4 and 5, respectively. As shown in Fig. 4, good coupling is observed between the copper and GBC TL(s).

On the other hand, the far-end coupling results shown in Fig. 5 depicts that there is better isolation between the two parallel copper TLs as compared to two GBC TLs. Overall, the measured far-end coupling in all cases of the proposed prototypes is -18 dB, which is still considered to be good for some designs.

IV. CONCLUSIONS

The wave propagation and coupling characteristics of graphene-based conductor (GBC) transmission lines (TL) are investigated and compared with copper TLs on a conformal surface. Experimental results showed that the GBC TLs have similar matching and transmission properties. Furthermore, near- and far-end coupling between two parallel GBC TLs were measured and compared against two parallel copper TLs and also with a GBC TL in parallel with a copper TL. The results showed that the use of GBC TLs could serve as an alternative to copper on a conformal surface, as good isolation and propagation can be achieved.

REFERENCES