An Initial Investigation on the Use of Carbon Microfibers for Conformal Transmission Lines

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***Abstract*—The use of carbon microfiber tow (or bundle) for conformal transmission lines (TLs) is initially investigated in this work. Two different microfiber TLs have been synthesized and tested. A 28.2 mm long microfiber TL was manufactured to demonstrate the wave propagating properties. Once these characteristics were determined, a microstrip TL was prepared by attaching 1oz conducting copper tape to a conformal surface and a similar microfiber TL with the same length and on the same substrate was manufactured. This prototype was then used to compare the propagation characteristics of the microfiber TL to the traditional and well established microstrip TL. Overall, it has been shown that the microfiber TL can support wave propagation in a manner similar to a microstrip TL; however, the attenuation constant appears to be rather large for frequencies above 500 MHz.**

I. Introduction

Conformal antennas can be used in wireless systems in a manner different than antennas on printed circuit boards (PCB). Because conformal antennas can be attached to singly or doubly curved surfaces [1]-[7], wearable clothing [8]-[20] or structures with vibrating surfaces [21]-[27] they have particular applications to vehicles, aircraft, sensors and search and rescue personnel. There are many challenges with the long term use of conformal antennas such as element failure, conductor breakage and substrate durability. To address these issues, many different research areas have been developed including antenna pattern distortion and correction due to various surface deformations [3], [8], [27], new flexible substrates [4] and unique manufacturing techniques [20].

Load bearing antennas have recently received attention [20] as a promising way to integrate microwave antennas into an existing structure without compromising the behaviour. One method to reinforce an overall structure is to selectively introduce carbon microfibers [28] to create a lightweight composite material that not only provide tensile strength, provide electrical properties as well. In this paper, the application of carbon microfibers to conformal (flexible) microstrip transmission lines (TLs) is initially investigated. A picture of the carbon microfiber tow (or bundle) considered in this work is shown in Fig. 1. Initially, the microfiber bundles are attached to a flat grounded substrate to create a microfiber TL. Then the propagation characteristics of this TL are investigated. The microfiber TL is next attached to a non-conducting sphere to investigate the TL properties on a conformal substrate. Finally, a traditional microstrip TL is manufactured and tested on a flexible substrate and compared to a microfiber TL with similar dimensions on the same substrate. By investigating the electrical properties of microfiber bundles, new methods for integrating embedded conducting TLs, antennas and RF electronics within composite materials may be explored.

Fig. 1. Picture of the microfiber bundle being considered in this work.

II. The Prototype Carbon Microfiber Bundle Transmission Line

The flexible bundle of microfibers in Fig. 1 was manufactured by Fibre Glast Development Corp. [28] and the fiber properties are summarized in Table I. To initially study

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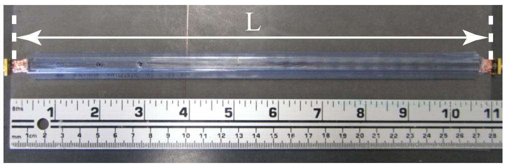
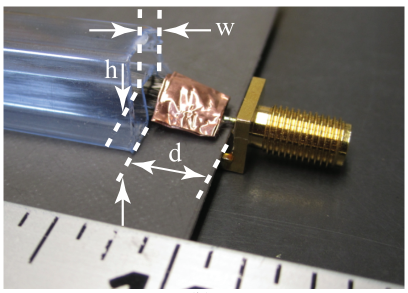
TABLE I
MICROFIBER PROPERTIES.

Tensile Strength (ksi)	610-700
Tensile Modulus (Msi)	33.6 - 34.9
Elongation %	1.85 - 2.10
Size Level %	1.00
Linear Density (w/size) (g/km)	1564
Density (g/cc)	1.82
Filament Dia. (μm)	7



(a)



(b)

Fig. 2. (a) Picture of the microfiber TL on a flat surface and (b) a closer image of the copper tape used to transition from the SMA connector to the microfiber TL (d = 10.0 mm, h = 5.0 mm, w = 4.0 mm and L = 28.2 mm).

the electrical properties of the microfibers, the prototype TL structure in Fig 2(a) was considered. The prototype TL consists of a flexible 0.787 mm thick Rogers RT/Duroid 5870 substrate ($\varepsilon_r = 2.33$, $\tan\delta = 0.0005$) with a ground plane on the bottom, while the microfiber TL was bundled and held together using a non-conducting plastic fixture and attached to the top of the substrate. The TL was then fed from the edge with the SMA connector shown in Fig 2(b). To transition between the center conductor of the SMA connector and the microfiber TL, 1oz copper tape was soldered to the center pin and wrapped around the microfibers. Finally, using an online microstrip TL impedance calculator, Z_o was computed to be approximately 30Ω. It was assumed that the conductors were ideal.

III. Initial Measurement Results

A. Single Microfiber TL Prototype on a Flat Surface

To explore the electrical properties of the microfibers, the TL was initially placed on a flat surface and the S-parameters were measured using an Agilent E5071C 100 kHz - 8.5 GHz ENA Series Network Analyzer. The results from these measurements are shown in Figs. 3-5. The S_{11} measurements in Fig. 3 show that for frequencies below approximately 2.0 GHz a better match is achieved (with the exception around 1.0 GHz). The S_{21} parameters shown in Figs. 4 and 5 show a -3dB point of 425 MHz and expected phase. For frequencies above 425 MHz the loss of the TL increases significantly.

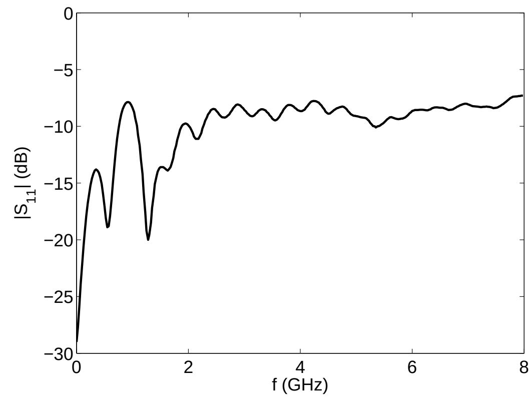


Fig. 3. Measured $|S_{11}|$ of the microfiber TL on a flat surface.

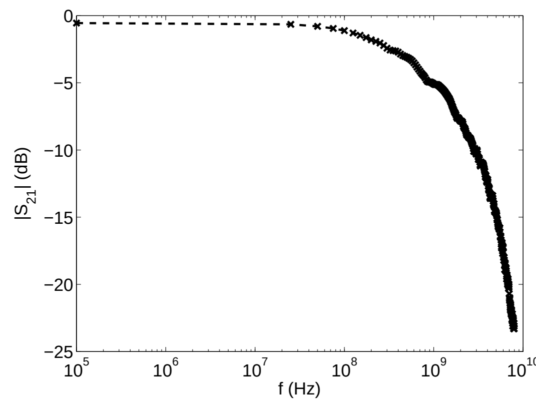


Fig. 4. Measured $|S_{21}|$ of the microfiber TL on a flat surface.

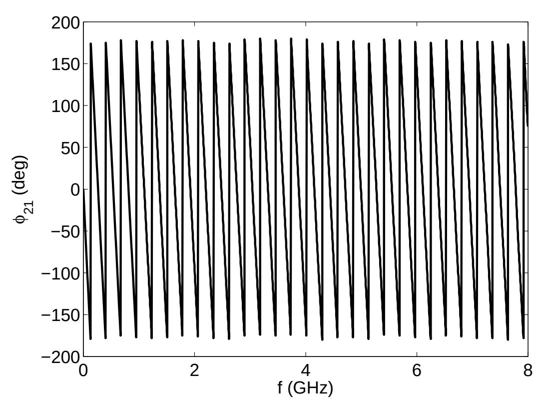


Fig. 5. Measured angle of S_{21} of the microfiber TL on a flat surface.

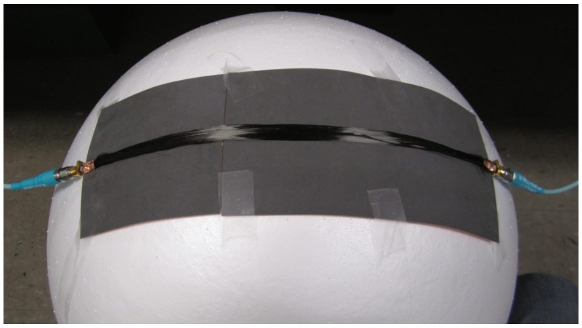


Fig. 6. Picture of the microfiber TL on a non-conducting styrofoam sphere.

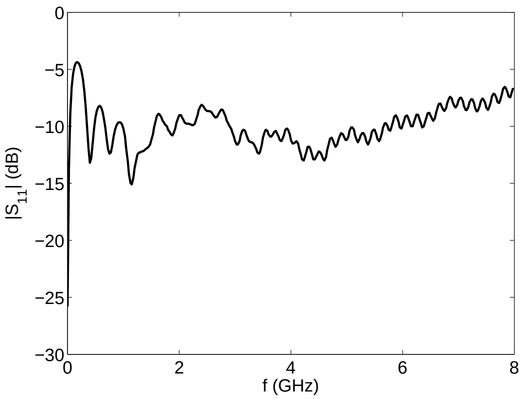


Fig. 7. Measured $|S_{11}|$ of the microfiber TL on a spherical surface.

B. Single Microfiber TL Prototype on a Curved Surface

Next, the prototype fiber TL in Fig. 2(a) was placed on a non-conducting sphere with a radius of 20.32 cm, as shown in Fig. 6. The S-parameters from these measurements are shown in Figs. 7 - 9. In a similar manner to the flat TL, the curved TL also has a fair match with the exception of frequencies below 600 MHz. On the other hand, the -3dB point was reduced to 100 MHz.

Overall, the spherical surface appears to affect the -3dB point and the lower matching frequencies of the fiber TL. This change is thought to be due to the radiation from the TL and the deformation of the microfiber conductors. As the TL conforms to the sphere, the width of bundle increases and the threads move closer (i.e., the threads are more compact).

C. Microstrip and Microfiber TL Prototype Comparison on a Flat Surface

For comparison purposes, a microstrip and microfiber TL was manufactured on the same 20 mil Rogers 5870 substrate as the microfiber TL in the previous subsections. The conductor for the microstrip TL was made using 1oz copper tape, as shown in Fig. 10. Using the Agilent network analyzer, the S-parameters were measured for each TL on a flat surface. The results from these measurements are shown in Figs. 12 - 14. Again, using an on line microstrip-line calculator, for the dimensions in Fig. 10 the characteristic impedance of the copper tape microstrip TL was determined to be 42Ω.

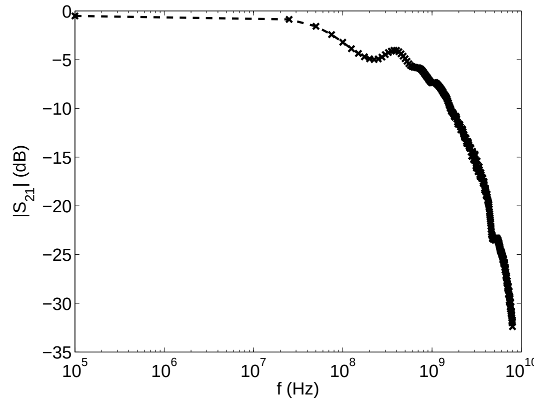


Fig. 8. Measured $|S_{21}|$ of the microfiber TL on a spherical surface.

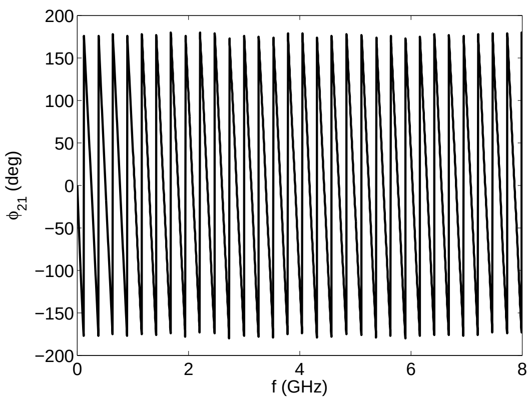


Fig. 9. Measured angle of S_{21} of the microfiber TL on a spherical surface.

D. Microstrip and Microfiber TL Prototype Comparison on a Curved Surface

Next, the prototype board with the microstrip and fiber TL was attached to a non-conducting surface with a radius of curvature of 10 cm and the S-parameters were measured. A picture of the prototype being measured is shown in Fig. 11 and the results are also shown in Figs. 12 - 14.

Overall, the fiber TL response was similar to the TL in Fig. 2(a). When compared to the microstrip TL with the copper tape, the matching is similar; however, the -3dB in the S_{21} plot is approximately 250 MHz for both cases.

IV. Discussion

The TL in Fig. 2(a) was chosen to be long enough to demonstrate wave propagation only. The measurements are used to simply illustrate that matching can be achieved, signal propagation from one port to the other can be observed and the phase constant is similar to the phase constant of a microstrip TL.

Since wave propagation was observed, the prototype board in Fig. 10 was then manufactured to compare the propagation characteristics of the fiber TL to the microstrip TL. It has been shown that matching can be achieved, and for frequencies

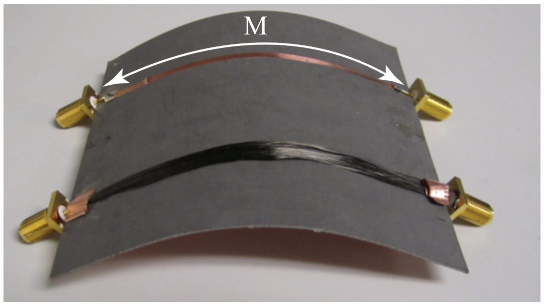


Fig. 10. Picture of the microstrip and microfiber TL on a conformal substrate (M = 92.0 mm).

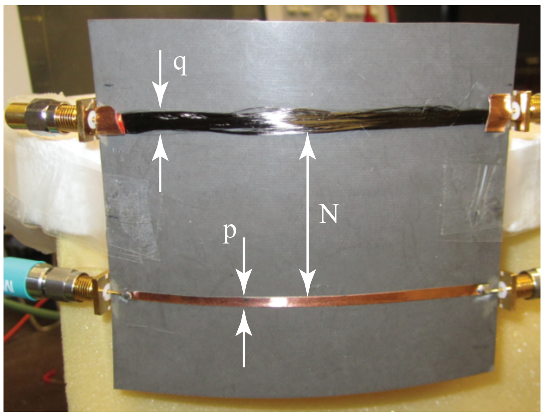


Fig. 11. Picture of the microstrip and microfiber TL being measured on a curved surface (N = 38.0 mm, p = 2.9 mm, q ≈ 5.0 mm).

below approximately 500MHz, the attenuation constant of the fiber TL may be low enough for some applications.

Finally, it should be mentioned that several microfiber TLs were manufactured with varying lengths and more densely packed carbon microfibers. The matching did not appear to be affected much by more fibers; however, the attenuation constant of the TL was reduced.

V. Conclusion

In this paper, two prototype microfiber transmission lines were manufactured and tested on various surfaces. First, a microfiber TL 28.2 mm long was synthesized and used to demonstrate wave propagation. Then, a microstrip TL with copper tape and a microfiber TL with the same length of the microstrip TL was manufactured and the S-parameters were compared on a flat and conformal surface. This comparison illustrated the difference between the microfiber TL and the conventional microstrip TL. Overall, it was determined that the matching characteristics of the microfiber TL are similar to the microstrip TL; however, the attenuation constant of the microfiber TL was much larger for frequencies above approx 500 MHz.

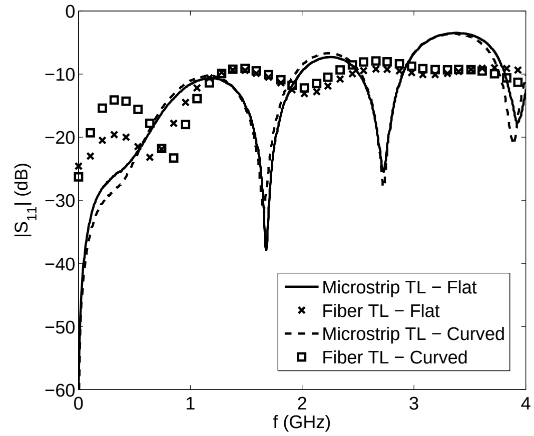


Fig. 12. Measured $|S_{11}|$ of the microstrip and fiber TL on a flat and curved surface.

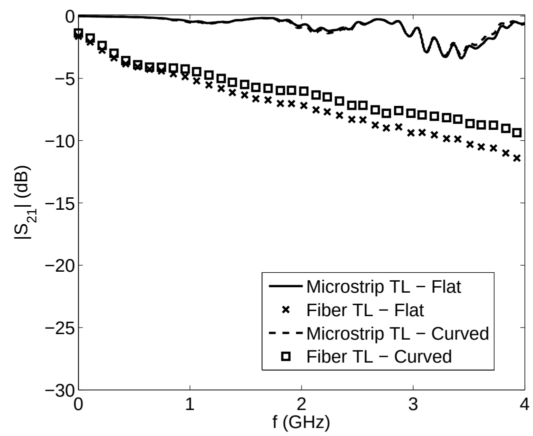


Fig. 13. Measured $|S_{21}|$ of the microstrip and fiber TL on a flat and curved surface.

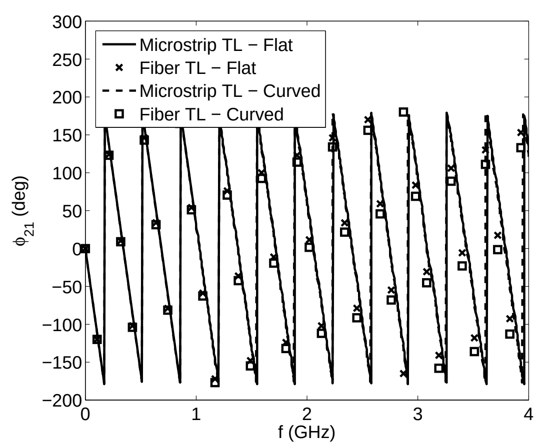


Fig. 14. Measured angle of S_{21} of the microstrip and fiber TL on a flat and curved surface.

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