On Using the Electrical Characteristics of Carbon Microfibers for Designing a Monopole Antenna

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***Abstract*—In this paper, the use of a carbon microfiber bundle (CMB) is investigated for manufacturing a monopole antenna. In particular, the radiating properties of a carbon microfiber bundle, having filaments of 7 μm in diameter, were studied as a monopole. The proposed monopole was mounted vertically on two separate types of ground plane, i.e., a small copper and a large aluminum ground plane. The monopole design was modeled in HFSS. To analyze the radiation characteristics of the microfibers and its shift in the resonant frequency, CMB monopole antenna prototypes with various lengths were manufactured and tested in an anechoic chamber. Overall, the simulation results agreed well with the measured results. Prototypes manufactured on the larger ground plane showed higher gain as compared to those on the smaller ground plane, with no significant difference in the matching characteristics. Overall, it was demonstrated that the light weight, low cost carbon microfiber bundle can be used to design an antenna for a range of resonant frequencies.**

I. Introduction

Researchers have been using metals such as copper and aluminum etc. as a radiating element in antennas because of their high conductivity. These metals however are considerably heavy, have poor corrosion resistance, and high manufacturing cost. Recently, some corrosion resistant conductive materials having low cost, high thermal conductivity have been used as an alternative to the copper [1]. Due to the light weight, easy fabrication, and good tensile strength, carbon fiber composites have been used as the radiating element in the antennas [2]. Also, carbon fiber reinforced plastic [3] and reinforced continuous carbon fiber composite [4] have been used to manufacture antennas. Furthermore, electrical properties of carbon microfiber bundle (CMB) have initially been investigated and its application as a transmission lines has been reported in [5].

In this paper, the use of CMBs [6] is explored to manufacture a monopole antenna for the very first time. More specifically, a CMB is used to manufacture a monopole antenna on two separate types of ground planes, as shown in Fig. 1(a) and (b). In order to demonstrate the radiating characteristics and its dependence of the monopole length, prototype monopoles with various lengths were manufactured and tested. The return loss and gain measurements showed that the carbon micro-fiber bundle can be used as an alternative to copper as it exhibits good impedance matching bandwidth and reasonable gain.

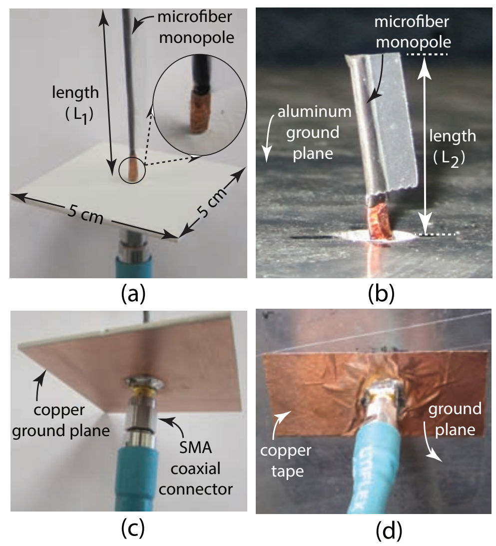

Fig. 1. Pictures of the proposed monopole antenna showing, (a) carbon microfiber bundle on a small copper ground plane, (b) carbon microfiber bundle on a larger aluminum ground plane, (c) SMA connector soldered to the copper ground plane, and (d) copper tape to secure connection between the SMA connector and an aluminum ground plane.

II. Design Procedure and Prototype Fabrication

The prototype monopole was built using the CMB, which is composed of 24,000 individual carbon filaments with an average diameter of 7 μm [6]. To perform the EM simulations and to verify the conductivity of the carbon microfiber bundle, a 50 Ω transmission line (TL) with a copper conductor was first modeled on a known TMM4 substrate and simulated in HFSS. Then, a 50 Ω TL with a carbon microfiber bundle on the same substrate was modeled instead of copper conductor and simulations were performed in HFSS. The modeled copper microstrip TL and microfiber TL were manufactured and measurements were taken. The S-parameters comparison of the simulation and measurement results over the frequency range of 100 KHz-3.5 GHz showed that good agreement exists for the determined conductivity (σ) of 1200 S/m. This value of conductivity was used to design the monopole antenna

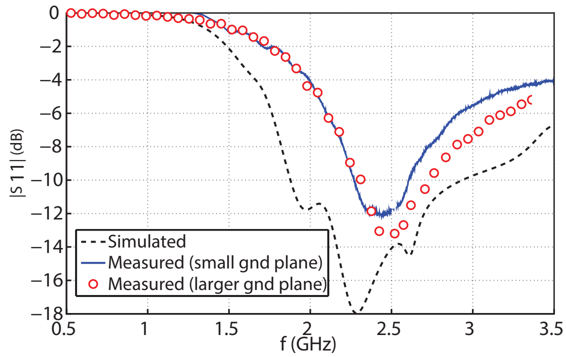

Fig. 2. Simulated and measured matching performance ($|S_{11}|$ (dB)) of the carbon microfiber monopole antenna on a small and a large ground plane.

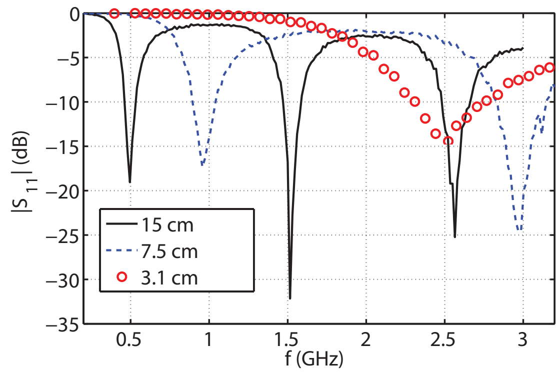

Fig. 3. Measured matching performance ($|S_{11}|$ (dB)) of the carbon microfiber monopole antenna with various lengths (L_2 = 15, 7.5 and 3.1 cm) on a large ground plane.

comprised of the carbon microfibers in HFSS, whereas a copper ground plane (5×5 cm^2) was used in the design.

The CMB was first twisted, stretched in a straight shape on a flat surface and then secured with the help of a scotch tape. The scotch tape gave additional strength to the microfiber bundle, allowing it to maintain a straight shape. This securely bundled yarn of carbon microfibers was then positioned vertically at the center of a separately prepared ground plane using a TMM4 substrate with 17.5 μm thick copper. Finally, the bundled yarn was connected to the SMA connector (connected using via from the ground plane) using copper tape, as shown in Fig. 1 (a). The ground of the SMA connector was soldered to the ground plane of the prototype, as shown in Fig. 1 (c).

In order to simulate an infinite ground plane in the measurements, the prototype monopole antenna was fabricated on a larger ground plane made of a 3 mm thick aluminum sheet, measuring 122 cm×21.5 cm. A picture of the monopole on the larger ground plane is shown in Figs. 1 (b) and (d), showing the radiating element and the ground plane, respectively.

III. Simulations and Measurement Results

A comparison of the simulated and measured results of the carbon microfibers based monopole on two different ground planes is shown in Fig. 2. Analytically, the resonant frequency of a monopole with a length of 3.1 cm should be $f_o = c/(4l) = 2.4$ GHz, which is in fair agreement with the simulated and measured results. All the measurements were taken in an anechoic chamber with a calibrated Keysight vector network analyzer (E5071C). Fig. 3 shows a parametric analysis of the length of the monopole antenna on a larger ground plane and demonstrates the resonance shift as the length of the monopole changes. Also, for the fundamental resonances at 500 and 950 MHz, harmonic frequencies can be seen in Fig. 3. The gain of the monopole with a length of 3.1 cm was measured on both the smaller and larger ground planes and found to be -3.6 and 2.5 dBi, respectively. The larger ground plane also showed better matching, but no significant difference in the resonance frequencies was observed.

IV. Conclusion

An initial investigation of a monopole antenna consisting of carbon microfibers was presented in this paper. The conductivity of the carbon microfiber bundle (CMB) was extracted by modeling in HFSS and then used to design and simulate the CMB based monopole antenna. The CMB based monopole antenna showed good radiating properties as observed in the simulations and measured results. Also, the CMB based monopole antennas having various lengths were manufactured and their $|S_{11}|$ (dB) results were measured, showing different resonant frequencies. It was demonstrated that the properties of the carbon microfibers can be used to design and fabricate monopole antennas and therefore can serve as an alternative to copper. Future research will be focused on the mechanical features and electrical properties of carbon microfiber composite antennas.

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