Effect of Carbon-Fiber Composites as Ground Plane Material on Antenna Performance

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Abstract — **The impact of carbon-fiber composites (CFC) as a ground plane material on antenna performance is investigated. CFC are lighweight materials that, due to their high mechanical durability, are increasingly used as chassis material for cars. Their electrical characteristics are anisotropic and dependent on the manufactured structure, which is expected to influence the radiation pattern. Simple monopole antennas for 2.45 GHz (ISM) and 5.9 GHz (ITS G5) are mounted to circular ground planes made of three different CFC and aluminum sheets. The influence on antenna performance is investigated with calibrated gain, return loss and the radiation pattern measurements.**

1 Introduction

Carbon-fiber composites (CFC) are lightweight, electric conducting materials with high mechanical durability. These materials consist of carbon fibers that are molded together with a matrix, typically an epoxy resin. CFC are in use as chassis materials in aeronautical and vehicular applications. Additionally to their application in Formula One and sports cars, the first mass produced cars with CFC parts are now commercially available. CFC replace aluminium and steel as antenna ground plane materials in vehicular communication.

It was shown that the structure of CFC (notably the orientation of the carbon fibers) leads to significant changes in the electric properties of such materials. In the direction of the fibers the electrical conductivity of CFC is determined by the amount of carbon fibers in the compound, transverse to the fiber axis the conductivity is reduced due to non-conductive epoxy [1, 2]. Like graphite, CFC are diamagnetic [3].

To improve corrosion resistance and reduce weight, slotted waveguide antennas made from CFC for maritime radar and space applications are investigated in [4, and references 4, 5 and 9 therein]. The CFC antenna had a similar radiation pattern but lower gain as its aluminum counterpart. The performance of slot antennas manufactured from CFC is compared to brass in [2]. In [5] it was found that the performance of antennas with unidirectional CFC depends greatly on the orientation of the material. This was utilized in [6] to build a mechanically reconfigurable antenna. Measurements of a patch antenna in [7] showed that the performance of woven CFC is similar to aluminum.

Vehicular antennas are usually mounted onto the roof and the ground plane material is set by mechanical considerations. Therefore, selection of different CFC due to their electrical properties might not be an option. The effect of CFC in the vicinity or as a ground plane material is investigated by measurements of simple monopole antennas on circular ground planes made from three different CFC for 2.45 GHz (ISM) and 5.9 GHz (ITS G5). The investigated carbon-fiber materials and the monopoles are described in Section 2. The measurement setup is described in Section 3 and the results are presented in Section 4. Finally, conclusions are drawn in Section 5.

2 Monopole antennas with CFC ground planes

Three different CFC are investigated in this paper. One ground plane (CFC1) has a thickness of 0.9 mm and consists of CFC with woven fibers and a fill level of approximately 45 %. Plies with a twill 2/2 weave with 1000 filaments per roving are stacked in five layers in a 45°/90°/45°/90°/45° orientation (Figure 1a). CFC2 has a thickness of 2.26 mm, it consists of plies with unidirectional fibers and has carbon snippets on the top to increase mechanical stability, it is depicted in Figure 1b. A 1.5 mm thick plate from CG TEC is denoted as CFC3, its plies consist of a 2/2 twill weave arranged as 0°/90° with a fiber volume of approximately 60 %. The aluminum ground plane has a thickness of 2 mm. All ground planes are circular and have a diameter of 195 mm.

The ground planes were threaded and screwed to SMA flange connectors (R125.403.000 W from Radiall). Copper wires with 1 mm diameter were then soldered to the inner conductor of the connectors. The length of the wires are trimmed to the right

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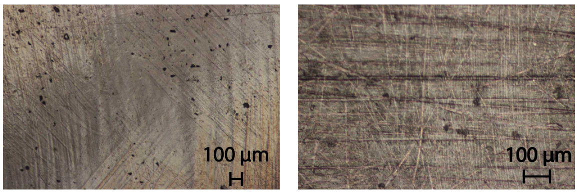
978-1-4673-5692-3/13/$31.00 ©2013 IEEE



(a) CFC1, woven structure (b) CFC2, unidirectional filaments

Figure 1: Microscopic photographs of the CFC. The top layer of CFC2 consists of unidirectional fibers that are visible as horizontal lines, with superimposed carbon-fiber shreds in no notable alignment, presumably to increase mechanical stability. CFC3 is not depicted as it has a structure similar to CFC1.

radiation frequencies by measuring the impact on the return loss, as depicted in Figure 4. The wire lengths are set for the aluminum ground plane and is kept for the CFC ground planes. The wire lengths were found to be 31 mm for 2.45 GHz and 13.6 mm for 5.9 GHz, including the protruding inner conductor of the connector. The monopole for 5.9 GHz is displayed in Figure 2 on the CFC2 ground plane.

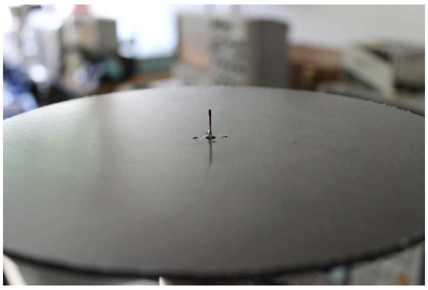


Figure 2: Monopole for 5.9 GHz on the CFC2 ground plane.

3 Measurement setup

Radiation patterns presented in Section 4 were obtained from spherical near-field measurements inside an anechoic chamber followed by a near-to-far-field transformation. The antenna under test is mounted to a column made of Rohacell IG31F foam on the φ rotary stage. The θ arm is equipped with a NSI-RF-RGP-10 probe and can rotate between 0° and 160°. The measurement setup is depicted in Figure 3. The monopole was mounted facing in z-direction ($\theta = 0$), in which also the polarization was measured. Gain calibrations were performed with NSI-RF-SG430 and NSI-RF-SG137 horn antennas.

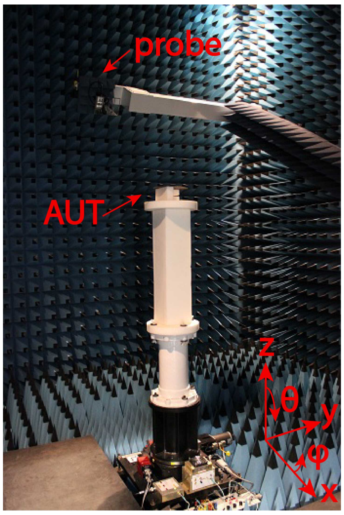


Figure 3: The antenna under test (AUT) is mounted onto a Rohacell column inside the near-field anechoic chamber.

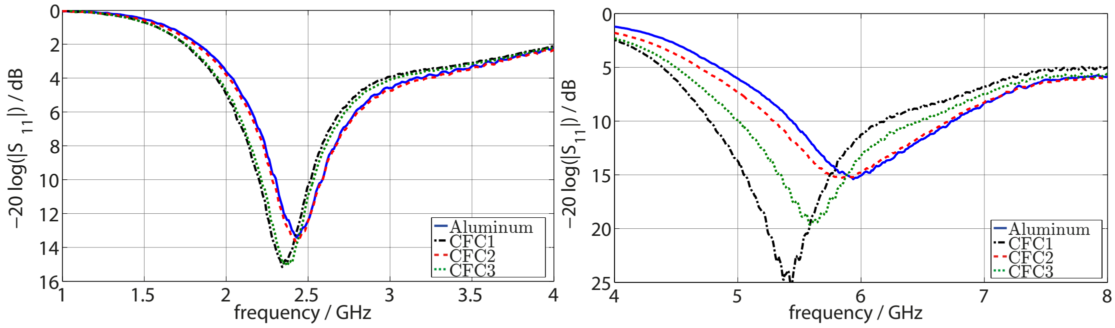
4 Measurement results

Return losses of the monopole antennas with CFC and aluminum ground planes are depicted in Figure 4. The substitution of the aluminum ground plane with CFC results in a shift in frequency and an increase in bandwidth of the monopole antenna.

The dependency of the normalized gain patterns on the polar angle θ for different ground plane materials is depicted in Figure 5. The normalized gain patterns of the monopoles with CFC ground plane are in good agreement with those made from aluminum. The deformation of the pattern in Figure 5b might be due to resonancy effects on the ground plane.

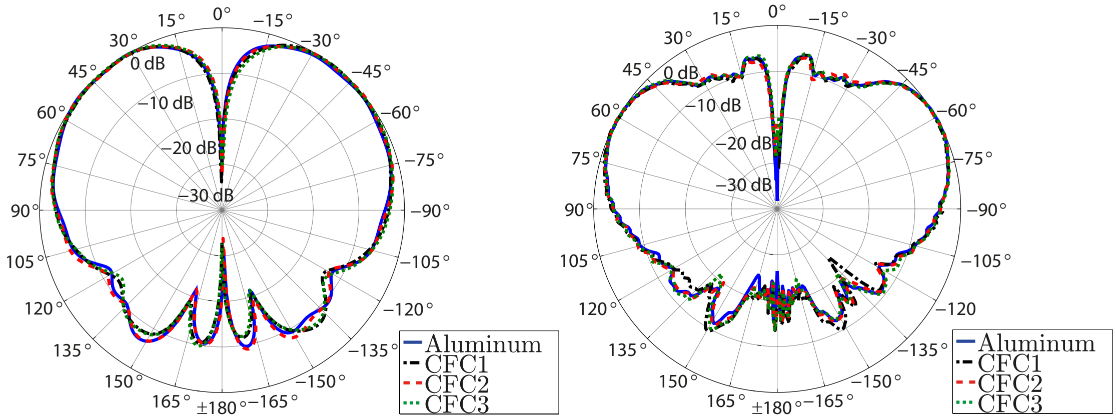
The gain patterns dependent on the azimuthal angle φ are depicted in Figure 6. The variation over φ is smaller than 1 dB for both 2.45 GHz and 5.9 GHz. Contrary to the assumption that radiation patterns might be skewed due to the anisotropic properties of CFC, a dependency on the orientation is not evident.

The measured antenna properties are summarized in Table 1. The efficiency of 102.3 % for CFC1 is due to measurement uncertainty, we expect an efficiency close to that of aluminum. The relative efficiencies of the CFC antennas decrease with increasing frequency. It should be noted that the reduced efficiency, that results from the application of a CFC ground plane, might not only be due to losses in the ground plane, but also due to poor contacting between connector and fibers. Proper contacting of carbon fiber rovings inside epoxy needs further investigation.



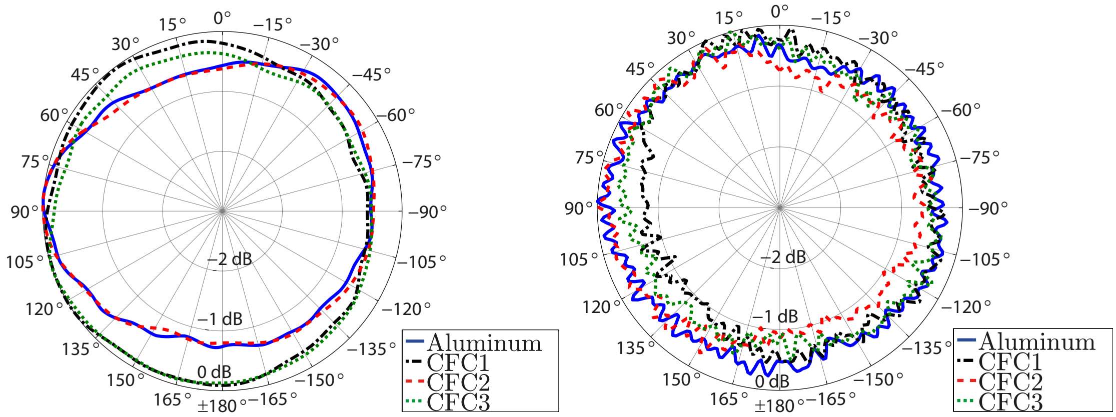
(a) Return loss of 2.45 GHz (ISM) monopoles (b) Return loss of 5.9 GHz (ETSI ITS G5) monopoles

Figure 4: Measured return loss of monopole antennas with different ground plane materials.



(a) Normalized gain pattern of 2.45 GHz (ISM) monopoles (b) Normalized gain pattern of 5.9 GHz (ETSI ITS G5) monopoles

Figure 5: Normalised gain patterns of monopole antennas with different ground plane materials. The field amplitude is shown in dependence of polar angle θ at azimuthal angle $\varphi = 0°$.



(a) Normalized gain pattern of 2.45 GHz (ISM) monopoles (b) Normalized gain pattern of 5.9 GHz (ETSI ITS G5) monopoles

Figure 6: Normalised gain patterns of monopole antennas with different ground plane materials in dependence of azimuthal angle φ at polar angle $\theta = 90°$.

2.45 GHz	Al	CFC1	CFC2	CFC3
10dB bandwidth [GHz]	0.29	0.32	0.31	0.32
relative 10dB BW [%]	11.8	13.1	12.7	13.1
maximum gain [dBi]	2.1	2.0	1.4	1.6
relative efficiency [%]	100.0	102.3	91.0	94.4
5.9 GHz				
10dB bandwidth [GHz]	1.30	1.42	1.43	1.48
relative 10dB BW [%]	22.0	24.1	24.2	25.1
maximum gain [dBi]	4.2	3.2	3.0	3.5
relative efficiency [%]	100.0	82.2	76.9	87.3

Table 1: Comparision of measured antenna properties with different ground plane materials.

5 Conclusion

We measured and discussed the impact of using CFC as the ground plane medium on monopole antenna performance. Three simple monopole antennas on circular ground planes were manufactured: Three monopoles on CFC ground planes and one on aluminum. Three different types of CFC are compared: two with woven fibers and one with unidirectional alignment of the fibers.

The radiation patterns show no dependency on the alignment of the fibers. The efficiency is slightly decreased in comparison to aluminum due to higher losses in CFC. Substitution of aluminum with CFC leads to a minor increase in bandwidth. The reduced efficiency might be partly reclaimed by improved contacting of the carbon fibers. We emphasize that CFC with different structure is expected to cause variations.

Overall the performance of monopole antennas on the investigated CFC ground planes is quite similar to aluminum sheets. From the measurements we conclude that the transition from aluminum to CFC ground planes in vehicular applications does not require a major redesign of antennas.

Acknowledgment

This work has been funded by the Christian Doppler Laboratory for Wireless Technologies for Sustainable Mobility. The financial support by the Federal Ministry of Economy, Family and Youth and the National Foundation for Research, Technology and Development is gratefully acknowledged.

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