# Performance of an Automotive Antenna Module on a Carbon-Fiber Composite Car Roof

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***Abstract*—The introduction of carbon-fiber composites in chassis production changed the materials in the vicinity of vehicular antennas. The two IEEE 802.11p antennas of an automotive antenna system are measured on a carbon-fiber roof and an aluminum sheet. Gain patterns are in good agreement, radiation efficiency on the carbon-fiber roof is about ten percentage points lower than on aluminum.**

***Keywords*—carbon fiber, vehicular, antenna, measurement**

## I. Introduction

Carbon-fiber composites (CFC) consist of electrical conducting carbon-fibers, that are usually held together by a non-conductive epoxy resin. CFC offer higher mechanical stability and reduced weight than metals like aluminum or steel. After their application in aeronautics, spaceflight, and sports cars, mass-produced cars with a CFC chassis are now feasible.

Electrical properties of CFC are anisotropic in general, with high conductivity in fiber direction and lower conductivity perpendicular to fiber direction [1]. In practice fiber strands are often woven into layers and are then stacked with rotated sheets to increase mechanical stability. Radio frequency properties of a CFC therefore also depend on the geometry of the material in relation to the wavelength.

Automotive antenna modules are about twenty centimeter long and about ten centimeter tall casings, that contain a variety of vehicular antennas and are located on the rear of the car roof. Common included services are mobile telephony, positioning systems, WLAN, car-to-car (C2C) and car-to-infrastructure communication and radio.

Performance differences between a CFC car roof and an aluminum sheet as antenna ground planes are compared with measured antenna matching, gain, efficiency and coupling of the C2C antennas in an automotive antenna module. The automotive module that is investigated in this paper contains a WLAN antenna, two UMTS Long Term Evolution (LTE) antennas, two IEEE 802.11p antennas and a GPS patch antenna. It is similar to those investigated in [2] and [3].

In previous work [4] no significant differences in the radiation patterns of monopole antennas for $2.45\,\mathrm{GHz}$ and $5.9\,\mathrm{GHz}$ on circular ground planes made from aluminum and three different CFC were found. However radiation efficiency was reduced by up to $23\,\%$, when replacing the aluminum ground plane with a CFC. In [5] similar results were found for rectangular ground planes and it was shown that radiation efficiency could be increased by a superimposed metallic ground plane, that can be manufactured as part of a molded interconnect device antenna design.

This paper is organized as follows: The antenna module, the carbon-fiber roof and the measurement equipment are presented in Section II. Measurement results are presented and discussed in Section III. In Section IV the results are summarized and implications for antenna use on carbon-fiber composite roofs are drawn.

## II. Measurement Setup

The performance of the antenna module is compared on two different ground planes. One ground plane is an unpainted carbon-fiber composite car roof. The roof consists of plies of unidirectional fibers and has a thickness of approximately $2.2\,\mathrm{mm}$. The other ground plane is a flat aluminum sheet. This results in different geometries of the two ground planes, however both ground planes are large compared to the wavelength of $5.1\,\mathrm{cm}$.

The car roof cutout and the antenna module have a different footprint. The cutout on the roof was broadened to fit the investigated antenna module. The roof was shortened in driving direction to fit the anechoic chamber at our institute.

The alumnium ground plane is a $1 \times 1\,\mathrm{m}^2$ sheet of standard aluminum with a thickness of $2\,\mathrm{mm}$. The fixture for the antenna module was laser cut from the center of the sheet. As the shape of the roof is usually different for each car model of a manufacturer, it is common practice to measure vehicular antennas on simplified roof models [6].

The automotive antenna module is about $15 \times 5 \times 7\,\mathrm{cm}^3$ large. The two IEEE 802.11p antennas are each placed on a printed circuit board (PCB) together with an LTE antenna and a matching network. The antenna in the PCB back of the module is denoted as C2C1, the antenna on the slightly smaller PCB in the center of the module is denoted as C2C2. The PCBs are vertically placed on a metal socket.

It should be noted that the electrical contact between the antenna module and the aluminum ground plane is good, as the protrusions around the module socket are pressed to the ground plane. The epoxy on the surface of the CFC roof however is an isolator and the exposed fibers in the cutout walls are not contacted, as there is an airgap in general. All measurements are performed with the antenna modules radome, unless noted otherwise. Unused antenna connectors were terminated with $50\,\Omega$.

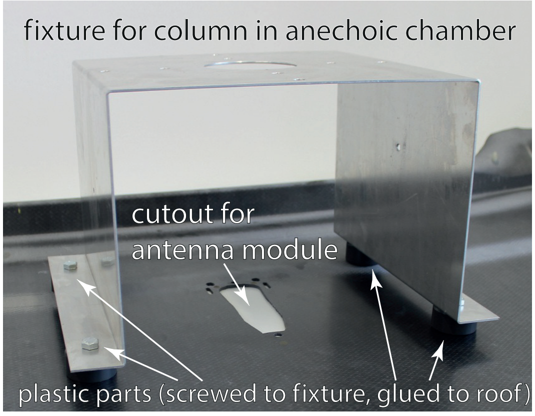



Fig. 1: The fixture to mount the roof onto the column in the anechoic chamber. The fixture can be removed for storage, allows easy access to the antenna module and doesn't require modifications to the top side of the roof.

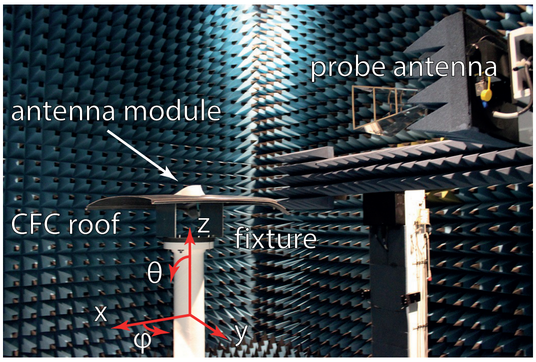



Fig. 2: The antenna module mounted on the CFC roof inside the anechoic chamber. In the coordinate system for the gain patterns, driving direction is defined as $\varphi = 0°$.

Threaded plastic parts were glued to the bottom of the ground planes. These parts can be screwed to a fixture that allows mounting in the antenna chamber without threading of the ground plane. Additionally, it is still possible to access the connectors of the antenna module once the ground plane is mounted. The antenna fixture on the roof and the roof fixture are shown in Figure 1.

Near-field measurements are performed inside the institutes anechoic chamber. Far-field results are obtained from a near-to-far-field transformation. Gain calibration is performed with NSI-RF-SG187 and NSI-RF-SG137 standard gain horns. An azimuth of $0°$ corresponds to the front of the antenna module (driving direction). The measurement setup in the anechoic chamber and the coordinate system for the gain patterns are depicted in Figure 2.

## III. Measurement Results

The measured S-parameters of the antennas are depicted in Figure 3. Return loss is about $20\,\mathrm{dB}$ for both C2C antennas and on both ground planes. Antenna isolation is about $30\,\mathrm{dB}$ or better.

The radiation efficiencies of the antennas are depicted in Figure 4. The efficiency of antenna C2C1 (Figure 4a) is about $10\,\%$ lower on the CFC roof than the efficiency on the aluminum sheet. This is smaller than the decrease in efficiency of $20\,\%$ found in [5] and $23\,\%$ in [4], where $5.9\,\mathrm{GHz}$ monopole antennas were placed directly on the CFC. For C2C2 the difference in efficiency is less than $10\,\%$ (Figure 4b). The reason that the efficiency is better than in previous investigations might be that the antennas are not directly placed on the CFC, as in practice they are in an elevated position above an aluminum socket.

The gain patterns dependent on polar angle $\theta$ are depicted in Figure 5. The gain patterns dependent on azimuth $\varphi$ for $\theta = 90°$ are depicted in Figure 6.

For car-to-car communication the shape of the gain pattern near the horizontal plane is important. The gain patterns for $\theta = 90°$ in Figure 6 show good agreement. The differences in the horizontal plane of C2C1 (Figure 6a) are: mean $1.07\,\mathrm{dB}$, median $0.94\,\mathrm{dB}$ and maximum $3.14\,\mathrm{dB}$. For C2C2 (Figure 6b) the differences are: mean $1.15\,\mathrm{dB}$, median $1.03\,\mathrm{dB}$ and maximum $5.88\,\mathrm{dB}$. The average and maximum differences between the whole patterns are mainly determined by small angular shifts in the zeros. The median differences in gain patterns for the complete sphere are $2.53\,\mathrm{dB}$ for C2C1 and $1.9\,\mathrm{dB}$ for C2C2.

The changes in gain patterns include both the influence of the different ground plane materials and the influence of the different shapes of the ground planes. In [4] the differences in the normalized gain patterns in the horizontal plane between for aluminum and CFC ground planes were smaller than $1\,\mathrm{dB}$.

As stated in [8] the radome has a significant effect on the radiation pattern of the antenna. The gain patterns of antenna C2C1 with and without radome are compared in Figure 7. Without the radome the difference between the aluminum sheet and the CFC roof is small as well. The radome has a larger influence on the gain pattern than the CFC roof.

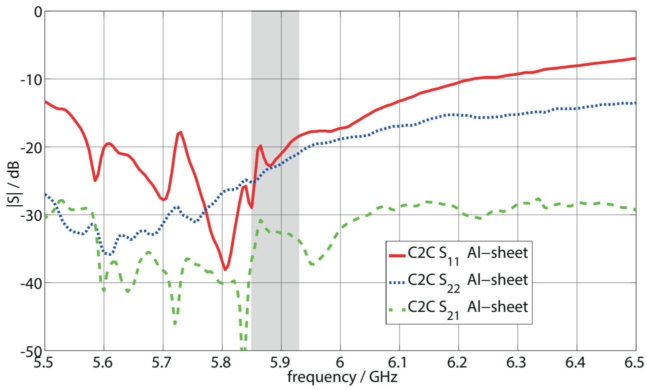
## IV. Conclusion

The performance of an automotive antenna module mounted on a CFC car roof is investigated with calibrated measurements of the gain patterns. As comparison the antenna module is measured on an aluminum sheet. The gain patterns for the two ground plane materials are in good agreement.

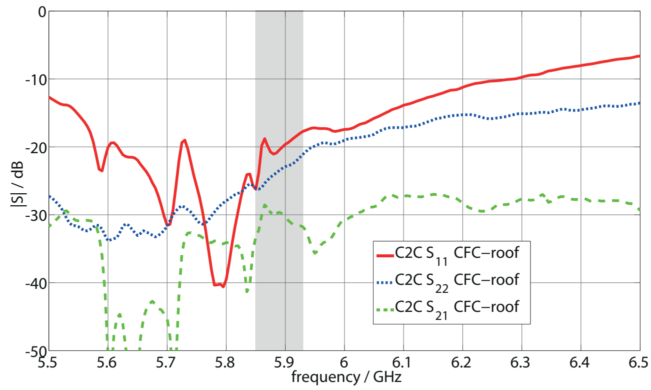
For example the presence of a panorama glass roof reduces the power radiated in the direction of the glass by up to $15\,\mathrm{dB}$ [7]. The influence of the CFC roof is smaller than the influence of the antenna radome (Figure 7, [8]) and is comparable to the influence of the roof curvature [9].

The reduction in efficiency due to the CFC ground plane is lower than in previous investigations [4], [5]. The reason might be, that the antennas are not placed directly on the CFC, but above the aluminum socket of the antenna module in an elevated position.

Overall the impact of the investigated carbon-fiber composite on the performance of the antennas is small compared to the influence of other effects on the performance of vehicular antennas.

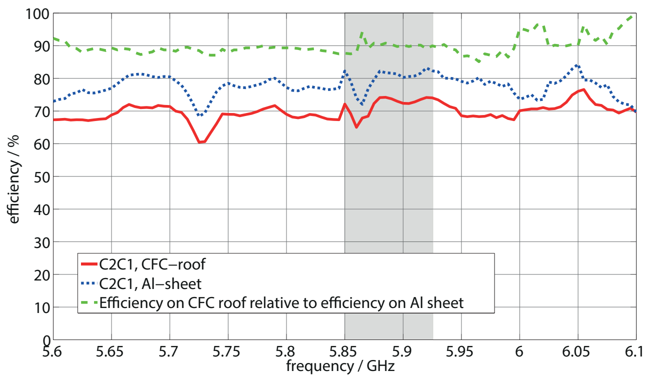



(a) S-parameters on aluminum sheet

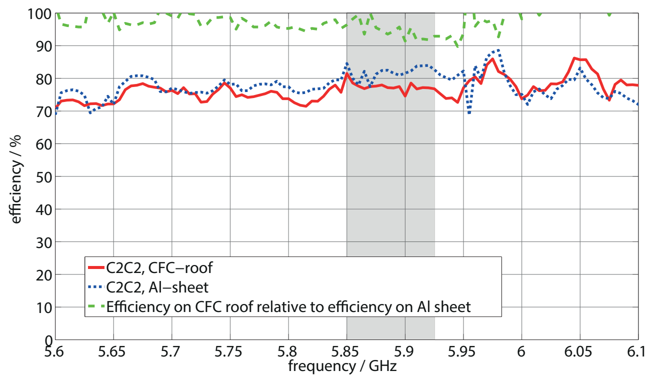



(b) S-parameters on CFC roof

Fig. 3: S-parameters for antennas on aluminium sheet and CFC roof. Antenna C2C1 was connected to port 1, C2C2 to port 2 of the vector network analyzer. $S_{11}$ and $S_{22}$ therefore are the negative return losses of antennas C2C1 and C2C2 respectively.

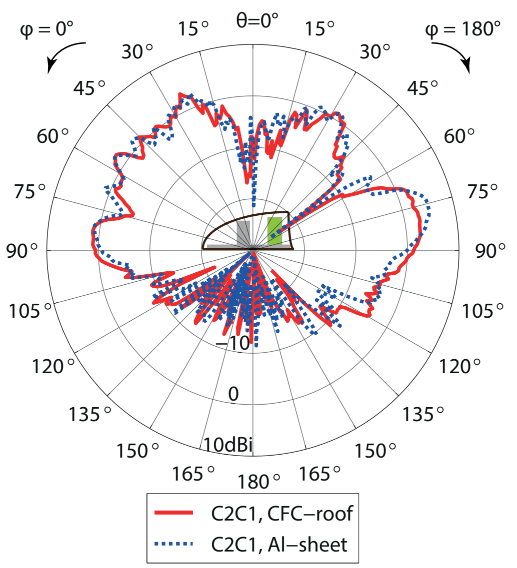



(a) Efficiency of antenna C2C1

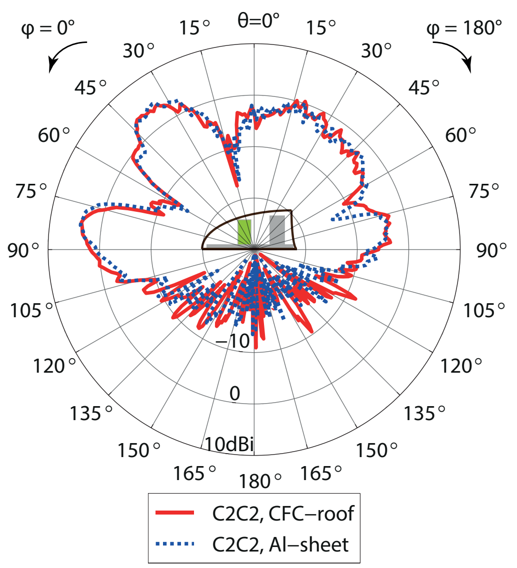



(b) Efficiency of antenna C2C2

Fig. 4: Efficiency of both car-to-car antennas with different ground plane materials.

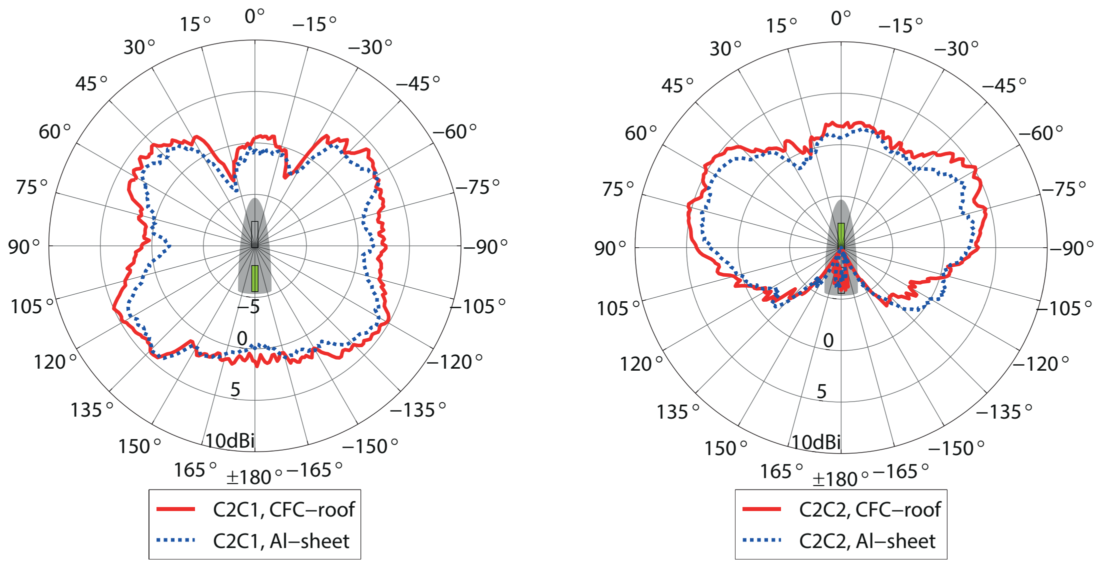



(a) Gain pattern of antenna C2C1




(b) Gain pattern of antenna C2C2

Fig. 5: Gain patterns of both car-to-car antennas with different ground plane materials. Dependence of polar angle $\theta$ at azimuthal angle $\varphi = 0°$ (left side) and $\varphi = 180°$ (right side).




(a) Gain pattern of antenna C2C1 (b) Gain pattern of antenna C2C2

Fig. 6: Gain patterns of both car-to-car antennas with different ground plane materials. Dependence of azimuth $\varphi$ at polar angle $\theta = 90°$.

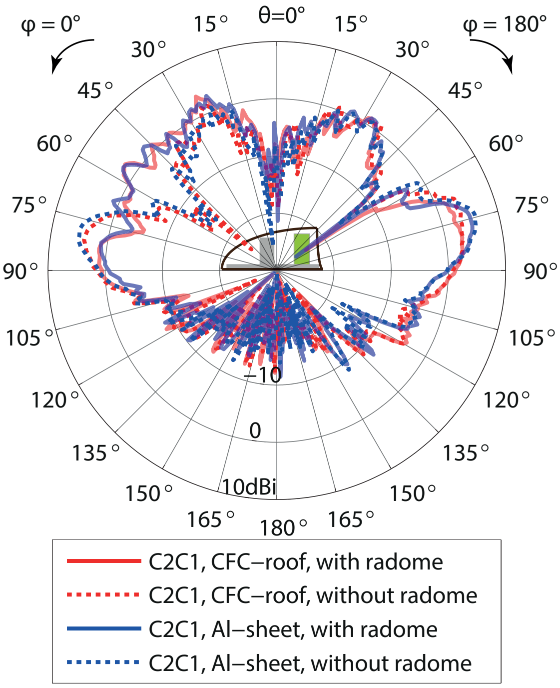



Fig. 7: Gain pattern of antenna C2C1 with and without radome on both ground planes. Dependence of polar angle $\theta$ at azimuthal angle $\varphi = 0°$ (left side) and $\varphi = 180°$ (right side).

We emphasize that the electrical properties of carbon-fiber composites vary with frequency and material structure. Composite materials with different ply structure might have a stronger influence on the radiation patterns of antennas in their vicinity.


## ACKNOWLEDGMENT

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