Carbon-Fiber Reinforced Antenna Cavity Hidden in the Monocoque of a Racing Car

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***Abstract*—A conformal antenna cavity for the monocoque of racing cars is proposed and prototyped from carbon-fiber reinforced polymer. Performance is evaluated with measured S-parameters and measured radiation patterns.**

I. Introduction

Racing cars use WLAN, GPS and recently also LTE to make real-time data from the car available in the cloud. Usually, simple protruding antennas are mounted on the chassis. However, antenna modules should not negatively influence the vehicle's drag coefficient, be light-weight and close to the mass center. Therefore, commercial shark-fin antennas are not applicable [1], [2]. Conformal chassis antenna cavities have recently been suggested for consumer cars and are investigated as alternative [3]–[6].

An antenna cavity is concealed in the monocoque of a Formula Student racing car. Formula Student fosters rapid prototyping, as teams build a new car every season. The prototype is built with carbon-fiber and glass-fiber reinforced polymer. It is measured and assessed with an off-the-shelf antenna.

II. Antenna Cavity for Racing Cars

The proposed antenna cavity is conformally built into the monocoque between the impact attenuator (crash box) and the front hoop. It is designed to fit in an inspection hatch, which is located at the front of the monocoque and above the acceleration and braking pedals. The computer aided design (CAD) drawing of the monocoque is shown in Fig. 1a. This position provides omnidirectional coverage and is only expected to be shadowed towards the back by the main hoop and rear wing. The size of the cavity is limited by the acceleration pedals underneath it, the width of the monocoque and to keep space for the drivers' legs, cables and board electronics that extend from the steering wheel into the front part of the monocoque. The final position is shown in Fig. 1b. The cavity is built with inclined walls, as in [3], [5], with a size of $110\,\mathrm{mm}\times120\,\mathrm{mm}$ at the cavity floor and $160\,\mathrm{mm}\times165\,\mathrm{mm}$ at the top. It is deeper at the front (24 mm), because the monocoque curvature, pedals and the drivers' feet allow less space at the back (20 mm). Overall, the design is a bit smaller than the LTE antenna cavity in [5].

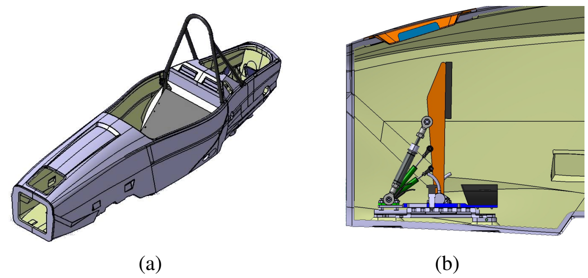


Fig. 1. a) CAD drawing of the racing car monocoque. b) Monocoque front part with the pedals and the antenna cavity above them.

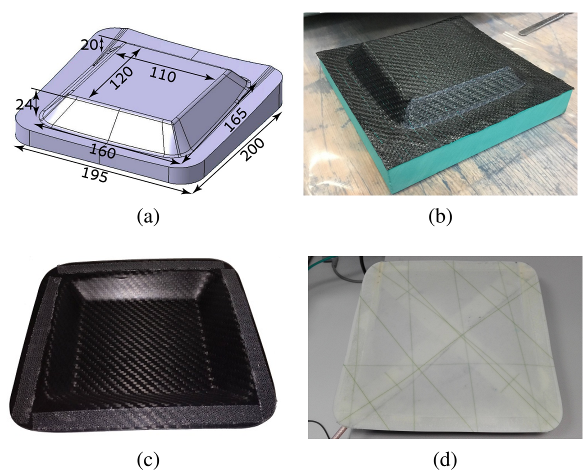
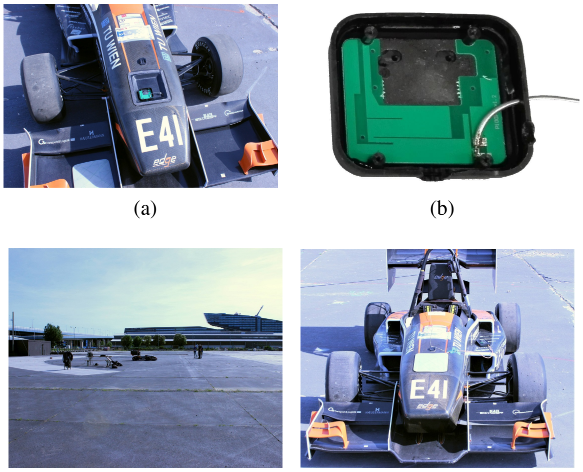


Fig. 2. The antenna cavity at various stages of production. a) CAD model of the mold, b) mold with prepreg before vacuum bagging, c) CFRP cavity and d) cavity with glass-fiber reinforced protective cover.

Racing cars use carbon-fiber reinforced polymer (CFRP) for lightweight construction. Additionally, CFRP are electric conductors and can be used as antenna ground plane [7]. A cavity prototype is manufactured from CFRP with the autoclave method. The mold (Fig. 2a) is milled from polyurethane block material, treated with wet grinding to smooth the surface and is sealed with varnish. The part is built as a laminate by stacking five layers of CFRP preimpregnated with epoxy resin (Fig. 2b). The prepreg is a twill-weave with a resin content of 45 % according to the supplier. The specimen is vacuum bagged and cured in an autoclave at 125°C and 6 bar for two hours. After autoclaving, the part is removed from the mold, cut to shape and deburred



(a) (b) (c) (d)

Fig. 3. a) EDGE 9 with the antenna cavity inserted into the monocoque. b) Off-the-shelf antenna that is used to evaluate the antenna cavity. c) Measurement of the radiation patterns on the outdoor range. d) Racing car with conformal antenna cavity.

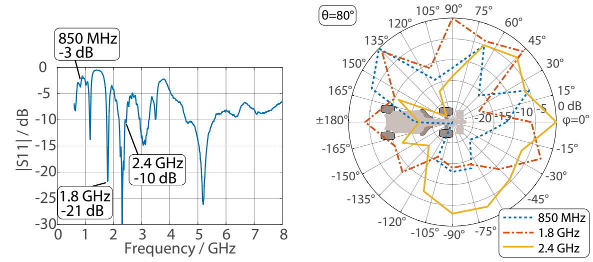
(Fig. 2c). A cover is built from glass-fiber reinforced polymer, again with the autoclave method (Fig. 2d). Strips of hook-and-loop fasteners are glued to the cover and cavity flange, such that it is resealable.

III. Antenna Measurements

The antenna cavity is built into the racing car EDGE 9 of the TUW Racing Team, which is shown in Fig. 3a. The prototype is evaluated by measuring an off-the-shelf antenna module, ATANTELPE LGG010L (Fig. 3b). It contains an active antenna for GPS and a passive antenna for LTE and WLAN. The GPS antenna is not further investigated, as the position provides unobstructed coverage towards zenith.

The racing car with the cavity, the antenna, and the cover is measured on the test track of the TUW Racing Team (Fig. 3c, Fig. 3d). The antenna is connected to a software defined radio (Hack RF), which generates a sinusoidal signal with constant frequency and amplitude. The signal-strength is measured in a circle around the antenna-under-test with a log-periodic antenna and a portable spectrum analyzer, such that the receive antenna is in the far-field. Angle-dependent received-power is normalized to obtain the antenna radiation patterns. The radiation patterns are measured at a polar angle $\theta = 80°$, because the antennas in the chassis cavity are close to the street, while the equipment of the racing teams is usually placed on a table next the race track.

The measured S-parameters are shown in Fig. 4a. The return loss at 850 MHz is 3 dB and could be improved. Return loss at 1.8 GHz and 2.4 GHz is good with -21 dB and -10 dB, respectively. Fig. 4b shows the measured radiation patterns. For 2.4 GHz WLAN, large changes of up to 24 dB are measured around the vehicle. The main hoop, driver seat and spoilers cause shadowing towards



(a) (b)

Fig. 4. a) Measured S-parameters of the off-the-shelf antenna inside the covered CFRP antenna cavity. b) Measured normalized radiation patterns; $\theta = 80°$; vertical polarization.

the back of the racing car. At 850 MHz, and to some extent at 1.8 GHz, the patterns are not symmetric towards the left and right side of the car, as would be expected because the car is symmetric (e.g. at 1.8 GHz for 30° gain is reduced by 18 dB). The reason is that the off-the-shelf antenna doesn't have symmetric patterns.

IV. Conclusion

For 2.4 GHz WLAN the antenna provides good coverage towards the front of the racing car, but towards the back it is shadowed by the main hoop and the spoilers, which results in 20 dB reduced gain. No clear conclusion can be drawn for the cavity at LTE frequencies, as the measured patterns include influences from the vehicle and the pattern of the antenna itself is not omnidirectional. We suggest to improve the performance of antennas at this location by using antennas with omnidirectional coverage towards the front and sides and by compensating the shadowing towards the back.

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