Carbon Fiber Reinforced Polymer Integrated Antenna Module

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Abstract — **Rising demand for vehicular communication and cooperative movement have led to an increase of vehicle mounted antennas. A carbon fiber reinforced polymer cavity is presented, that can be integrated into the vehicle chassis. The concealed cavity is large enough to house the anticipated antennas for present and future vehicular communication. Influence of the cavity onto antennas is demonstrated with calibrated gain measurements on the example of a 5.9 GHz monopole antenna for intelligent transportation systems. The cavities impact on antenna performance is found to be much smaller than influences of the car itself.**

1 INTRODUCTION

Vehicles house a large variety of antennas to ensure reliable communication with their surroundings at radio frequencies (RF). Typical services include positioning systems, mobile communication, reception of television and radio programs, broadcasting of emergency messages, radar, and machine-to-machine communication to enable cooperative movement with other vehicles.

Protruding antenna modules increase the drag coefficient of vehicles, get damaged more easily and their aesthetics are a concern for consumer products (e.g. automotive modules on car roofs [1]). Concealed antenna modules allow antenna development independent from mechanical and aerodynamic considerations. An automotive concealed antenna for Satellite Digital Audio Radio Services (SDARS) inside a 40 mm × 40 mm × 10 mm cavity, along with measured gain patterns and a test drive, was presented in [2]. Automotive antennas are also built into the windows and bumpers [3] and side mirrors [4]. An antenna for an aircraft distance measurement equipment (DME) inside a cavity is presented in [5].

A large cavity antenna module is proposed which can be manufactured as part of the vehicle chassis. The cavity is big enough to house already existing concealed antenna designs and provides enough space to meet future requirements. A prototype made from carbon fiber reinforced polymer (CFRP) is presented to show the feasibility of such a cavity from both a mechanical and high frequency standpoint.

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2 CARBON FIBER REINFORCED POLYMER

Carbon fiber reinforced polymer (CFRP) is a composite material consisting of reinforcing fibers in a continuous polymer matrix. This material class is one of the biggest advancements in the field of light weight structural materials. Especially the mobility sector uses the advantages of CFRP such as high stiffness and strength, low density (1600 $\mathrm{kg/m^3}$), corrosion and chemical resistance and absorption of energy (crash elements).

At the beginning of the production process a mold is needed, in which the fiber material is getting combined with the polymer resin system. The curing can also be done in this mold. There are many different technologies available to perform this production step. The aeronautical industry and the motor sport industry use preimpregnated materials (prepreg) and an autoclave for the curing. That way, a low and constant resin content is achievable, but the efforts for this technology are high. Especially the automotive industry, which has to produce thousands of pieces per part, is trying to use other technologies like the resin transfer molding (RTM). RTM starts with a dry fiber system that is called preform. This preform has optimized fiber amounts and orientations. In the mold the preform is getting infiltrated with the resin system and the chemical reaction starts. At the moment cycle times of some minutes are achievable with this technology.

After this production step the parts have to be mechanically machined to get the necessary part dimensions or to trim resin canals before the assembly can be done. These process steps are also necessary due to the behavior of CFRP demand and the cost intensity. During the machining damages like fraying, delamination or splintering [6] can occur. Another problem is the highly abrasive character-

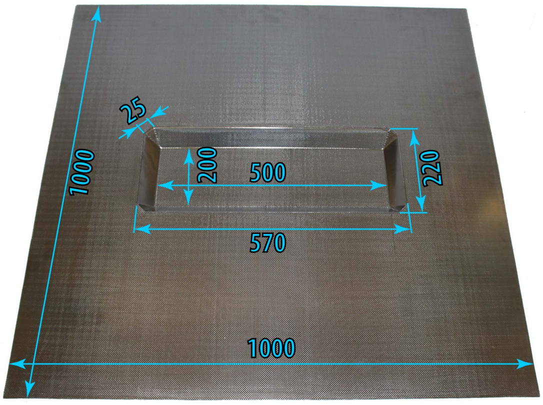

Figure 1: CFRP prototype of the antenna module, debagged specimen after the curing in the autoclave. All dimensions are in millimeter.

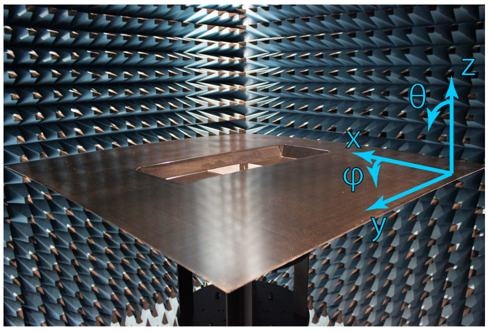

Figure 2: LDS monopole antenna inside the CFRP integrated chassis module. The depicted coordinate system is displaced to increase visibility, the origin is in the center of the cavity.

istic of CFRP [7] which is dependent on the higher tool wear in comparison to the machining of steel or aluminum. So there are many additional efforts in comparison to the production process of metallic parts, which have to be managed before the fiber reinforced polymer can create benefits out of the material advantages.

Like its mechanical properties, the electromagnetic properties of CFRP are a mixture of its components. The carbon-fibers are (poor) electric conductors, the matrix is typically a dielectric. The conductivity of CFRP is frequency dependent and anisotropic [8]. In practice often woven plies are used and the RF properties of the final part then also depend on ply weave and layup. Measurement results of a patch antenna on a CFRP ground plane and a slot antenna in CFRP are presented in [9]. For three CFRP ground planes the influence on the radiation patterns of monopole antennas for 2.45 GHz and 5.9 GHz were found to be negligible [10]. Measurements of the two vehicle-to-vehicle (V2V) antennas in an automotive antenna module mounted on a CFRP car roof are presented in [11]. Only small differences in performance due to the CFRP roof were measured.

3 THE ANTENNA MODULE

The used specimen geometry for the experiments is a plate with 1 m$\times$1 m and a central rectangular cavity with inclined walls. Dimensions are depicted in Figure 1. All edges are manufactured with a radius of 5 mm. The cavity offers significantly more space than current automotive antenna modules. Not only does the cavity provide enough space for the antennas of future vehicular services, it also allows to move RF hardware close to the antennas, thus eliminating the need to route coaxial cables. Furthermore, antennas can be better separated.

The autoclave method was chosen to produce high quality components. As mold material a Raku-Tool WB-0700 tooling material is used. The geometry was automatically produced with a machining center. Before the production of the layup the mold is treated with the Chemlease MPP 712 EZ and the Chemlease PMR EZ to create a sealed surface.

The composite part is constructed orthotropic with two fiber axis at 0 and 90 degrees. The used material is an Isovolta prepreg with 200 g/m^2 area weight, plain weave and an epoxy resin with intermediate coefficient of glass temperature. There are eight layers of this fabric stacked as $[(0°/90°)_4]$ to produce a part thickness of around 2 mm. The resulting resin content is about 30 percent. The curing is done in an autoclave at 4 bar and 130 °C for 3 hours. Four specimen are produced this way to generate constant part behavior for further experiments. One of the specimen is shown in Figures 1 and 2.

4 ANTENNA MEASUREMENTS

In this section measurement results for a 5.9 GHz monopole antenna for V2V communication are presented. The antenna was manufactured with the laser direct structuring (LDS) process from LPKF and is mounted on a square aluminum ground plane with 150 mm side length. The additional ground plane is used because proper contacting of the thin CFRP sheet is hard and to negate a possible reduction in radiation efficiency due to losses in a CFRP ground plane [12]. Calibrated gain measurements were performed inside the institutes anechoic chamber. The CFRP cavity prototype with the

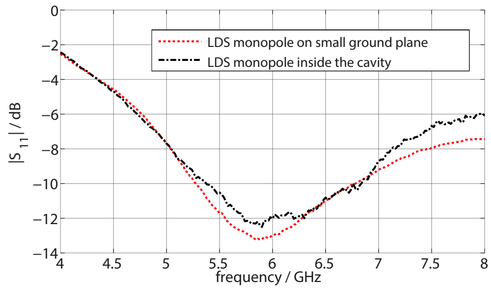

Figure 3: $|S_{11}|$ of the monopole antenna on the aluminium ground plane and inside the cavity.

monopole antenna inside the anechoic chamber is depicted in Figure 2. The return losses of the LDS monopole antenna in free space and the antenna inserted into the cavity are depicted in Figure 3.

Vertical cuts of the gain patterns are shown in Figures 4 and 5. Due to the larger ground plane size radiation with the cavity is more concentrated in the upper hemisphere. Additional zeros appear for small polar angles θ in the gain pattern, when the monopole is inserted into the cavity. A zero at zenith is typical for monopole antennas. In direction of the smaller cavity dimensions ($\varphi = 0°$ and $\varphi = 180°$) radiation is good for polar angles θ as small as 20°. Towards the larger cavity dimensions ($\varphi = 90°$ and $\varphi = -90°$) first deep notches appear for polar angles smaller $\theta = 45°$. The additional zeros close to zenith have no impact on V2V communication for intelligent transportation systems (ITS). In both cases communication with larger vehicles and roadside infrastructure is certainly possible.

The gain pattern in the horizontal plane ($\theta = 90°$) is shown in Figure 6. Although the antenna is placed in a cavity below the CFRP sheet, horizontal radiation is comparable to free space. The gain pattern of the monopole antenna inside the cavity has ripples of about 4 dB. This is satisfactory for automotive applications as vehicle geometry affects gain patterns in a similar, or larger magnitude. At the same frequency the influence of optional elements like roof rails is in the same magnitude [13]. Roof windows cause up to 10 dB notches in the radiation pattern [13]. The geometry of the antenna radome may vary between car models and its influence on gain patterns can be compensated [14].

5 CONCLUSION

A cavity was presented which can be manufactured as part of a vehicles chassis. The cavity offers enough space for currently required vehicular antennas and is large enough to contain future an-

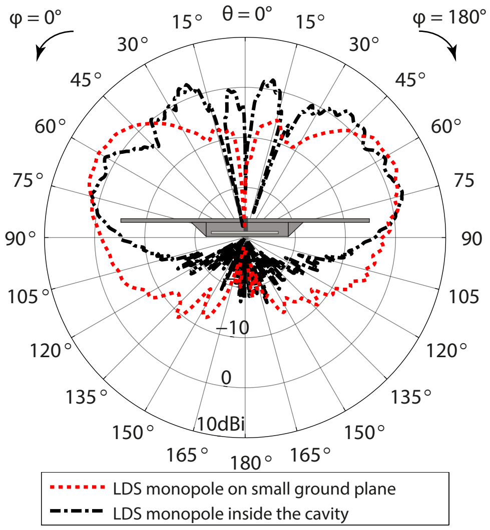

Figure 4: Gain pattern of the monopole antenna in free space and inside the cavity. Elevation cut dependent on polar angle θ for $\varphi = 0°$.

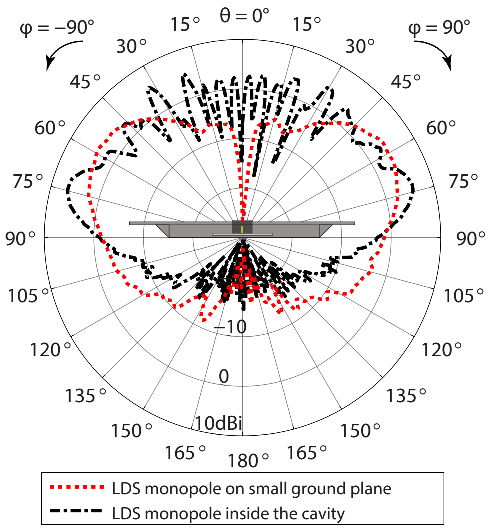

Figure 5: Gain pattern of the monopole antenna in free space and inside the cavity. Elevation cut dependent on polar angle θ for $\varphi = 90°$.

tennas required for additional services and antenna diversity. It enables manufacturers to move RF equipment closer to the antennas, eliminating the need to route coaxial cables. The drag coefficient c_w of the vehicle is not deteriorated and the antennas are concealed.

The feasibility to manufacture the cavity as part of a chassis was demonstrated by producing a CFRP prototype. The feasibility to use the cavity as an antenna module was demonstrated with measured gain patterns of a monopole antenna inside the module. The measurement results show

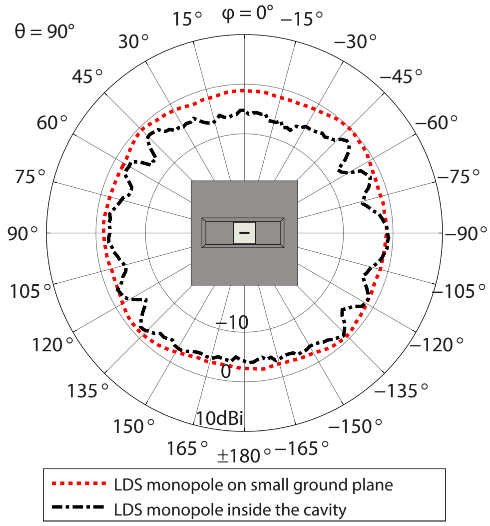

Figure 6: Horizontal cut of the gain pattern dependent on azimuthal angle φ for $\theta = 90°$

that omnidirectional radiation with the proposed antenna module is possible and reliable communication during cooperative driving is feasible.

Acknowledgment

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References

[1] E. Ghafari, A. Fuchs, D. Eblenkamp and D.N. Aloi, “A Vehicular Rooftop, Shark-fin, Multiband Antenna for the GPS/LTE/cellular/DSRC Systems”, *IEEE-APS Topical Conf. on Antennas and Propagation in Wireless Commun. (APWC)*, Palm Beach, Aruba, 2014

[2] J. Kammerer and S. Lindenmeier, “Invisible Antenna Embedded in the Roof of a Car with High Efficiency for Reception of Satellite Digital Audio Radio Services (SDARS)”, *European Conf. on Antennas and Propagation (EuCAP)*, Gothenburg, Sweden, 2013

[3] R.J. Langley and J.C. Batchelor, “Hidden antennas for vehicles”, *Electronics & Commun. Eng. J.* 14, 2002

[4] S. Senega, J. Kammerer and S. Lindenmeier, “Scan-Phase Antenna Diversity for Digital Satellite Radio (SDARS) in a Single Automotive Side Mirror”, *European Conf. on Antennas and Propagation (EuCAP)*, The Hague, The Netherlands, 2014

[5] L. Rufail and J. Laurin, “Aircraft Cavity-Backed Nonprotruding Wideband Antenna”, *IEEE Antennas Wireless Propag. Lett.* 11, 2012

[6] R. Zemann, J. Sacherl, W. Hake and F. Bleicher, “New Measurement Processes to Define the Quality of Machined Fibre Reinforced Polymers”, *25th DAAAM Int. Symp. on Intelligent Manufacturing and Automation*, 2014

[7] R. Zemann, F. Bleicher, “Challenges in the field of machining fibre reinforced polymers”, *Vienna young Scientists Symp. (VSS)*, ISBN: 978-3-9504017-0-7, 164 - 165, Vienna, Austria, 2015

[8] H. C. Kim and S. K. See, “Electrical properties of unidirectional carbon-epoxy composites in wide frequency band”, *J. of Physics D: Appl. Physics* 23.7, 916, 1990

[9] A. Galehdar, W. S. Rowe, K. Ghorbani, P. J. Callus, S. John, and C. H. Wang, “The effect of ply orientation on the performance of antennas in or on carbon fiber composites”, *Progress in Electromagnetics Research* 116, 123-136, 2011

[10] G. Artner, R. Langwieser, G. Lasser and C. F. Mecklenbräuker, “Effect of Carbon-Fiber Composites as Ground Plane Material on Antenna Performance”, *IEEE-APS Topical Conf. on Antennas and Propagation in Wireless Commun. (APWC)*, Palm Beach, Aruba, 2014

[11] G. Artner, R. Langwieser, “Performance of an Automotive Antenna Module on a Carbon-Fiber Composite Car Roof”, *European Conf. on Antennas and Propagation (EuCAP)*, Davos, Switzerland, 2016

[12] G. Artner, R. Langwieser, C. F. Mecklenbräuker, “Material Induced Changes of Antenna Performance in Vehicular Applications”, *IEEE Int. Conf. on Microwaves, Commun., Antennas and Electronics Systems (COMCAS)*, Tel Aviv, Israel, 2015

[13] A. Kwoczek, Z. Raida, J. Lacik, M. Pokorny, J. Puskely and P. Vagner, “Influence of Car Panorama Glass Roofs on Car2Car Communication (Poster)”, *IEEE Veh. Networking Conf. (VNC)*, Amsterdam, The Netherlands, 2011

[14] L. Ekiz, T. Patelczyk, O. Klemp and C. F. Mecklenbräuker, “Compensation of Vehicle-Specific Antenna Radome Effects at 5.9 GHz”, *Annu. Conf. of the IEEE Industrial Electronics Soc. (IECON)*, Vienna, Austria, 2013