Exchangeable Bases for Rapid Prototyping of Carbon Fiber Reinforced Polymer Antenna Cavities

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Abstract — **Chassis antenna cavities were recently introduced as large, hidden, antenna modules. Testing different antenna configurations inside the module would require cutting several holes into the cavity floor. Manufacturing of several prototypes is not feasible, especially for carbon-fiber reinforced polymer chassis; flexible solutions are desired. Exchangeable cavity bases for chassis antenna cavities are proposed, designed and manufactured. Antenna measurements show the feasibility of the concept.**

1 INTRODUCTION

Chassis antenna cavities have recently been proposed for concealing antenna modules inside vehicles' hulls [1]. A prototype of a chassis cavity was manufactured from carbon fiber reinforced polymer (CFRP) and it was shown that near-omnidirectional radiation from the cavity is possible with monopole and inverted-F antennas. In [2] it was proposed to use chassis cavities in automotive applications. The cavity replaces roof mounted shark-fin modules, and keeps the car roof as preferred antenna location. Such a cavity is preferable over hidden antenna placement in side or rear view mirrors, spoilers, roof pillars, etc. as it is dedicated antenna space, which allows antenna design independent from other functional units. A pattern reconfigurable antenna inside a chassis antenna cavity, which can be electronically switched to radiate towards the front, back, left or right side of a car, is measured in [3].

The chassis antenna module follows the design paradigm to conceal automotive antennas. By hiding the antennas in the vehicle hull, the antennas no longer influence the drag coefficient or the aesthetic design of the vehicle. An aperture in the roof was proposed in [4]. [5] presents a stacked combination of a Satellite Digital Audio Radio (SDARS) and Global Positioning System (GPS) antenna. Antennas in truck side mirrors are described in [6]. Conformal antennas on a car side mirror are designed in [7]. A telephony and WLAN antenna hidden on the rear roof end is developed and measured in [8].

A very practical problem appears when measuring antenna prototypes inside chassis antenna cavities. The cables of the antennas need to be connected through the cavity bottom or the cavity walls. This requires, that a hole is cut into the cavity in order to connect the antennas with the measurement equipment in the anechoic chamber. Measurements of multiple antennas in the cavity or measurements at different locations are therefore not possible, as too many holes will alter the results. Manufacturing of large CFRP parts is quite expensive, as the laminate needs to be laid by hand and cured in an autoclave. Building a separate cavity prototype for each measurement would be expensive and unreasonable. In mass production this is not an issue as the positions of the antennas are then already fixed.

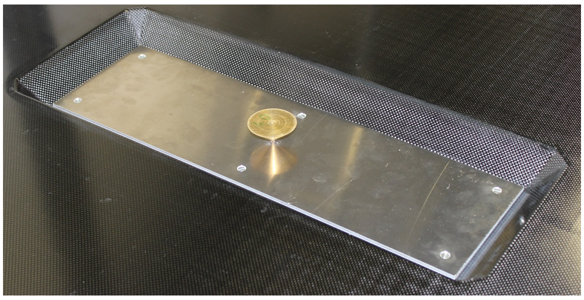

Figure 1: Assembled setup with CFRP chassis cavity, exchangeable aluminum base and conical monopole antenna.

Exchangeable cavity bases are proposed for the rapid prototyping of antennas inside chassis cavities (Fig. 1). Exchangeable metal bases are cheap and fast to manufacture, as they can be laser cut. Using a metal of sufficient thickness allows attachment of coaxial cable flanges to the cavity base, which is not possible with thin CFRP sheets. Previously, the flanges were attached to an additional metal ground plane that was then placed inside the cavity (see [1-3]). The bases can be used in drive tests as the bases and antennas are securely attached with screws. With the proposed method it is also possible to attach advanced prototypes of whole antenna modules inside chassis cavities, which also contain radio frequency hardware, structures for antenna decoupling, protective cover, etc.

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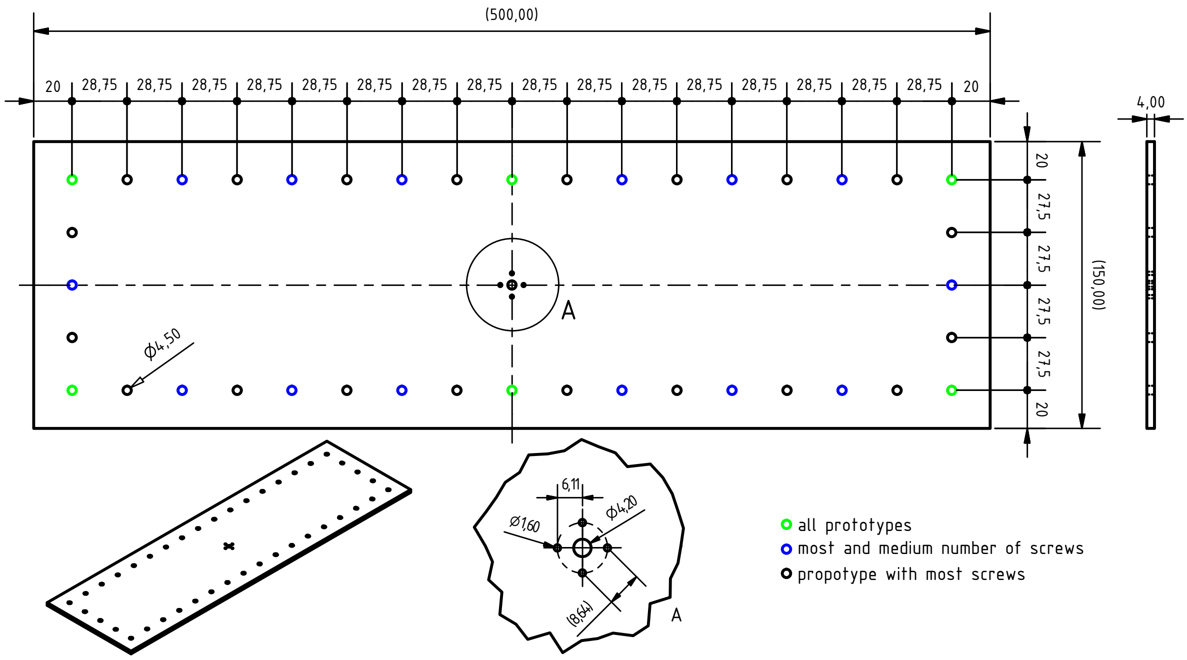

Figure 2: Technical drawing of the exchangeable cavity bases. All dimensions are in millimeter.

2 EXCHANGEABLE CAVITY BASES

The floor of the CFRP cavity from [2] is replaced by rectangular, exchangeable, metal plates. The plates are fastened to the cavity with counter-sunk screws along the plates' borders. Such plates are cheap and fast to manufacture with laser cutting. To show feasibility, a conical monopole is measured in the center of the cavity. This was done in [2] to obtain a broadband characterization of the influence of the antenna cavity on monopole antennas. But note that in [2] the conical monopole antenna needed to be placed on a separate metal ground plane, which was lowered into the cavity and placed on the cavity floor, as the CFRP sheet was too thin to thread and attach flanges. In this paper the conical monopole antenna is measured again, but this time the broadband measurements are used to compare exchangeable cavity bases to the results from [2]. Coaxial cables are again connected with Subminiature Version A (SMA) coaxial connectors. This time the flanges are directly screwed to the cavity bases. A technical drawing of the exchangeable cavity bases is depicted in Fig. 2. Three exchangeable base prototypes were built, which use different amount of screws. Only the holes shown in green in Fig. 2 are used for the base with the least amount of screws, green and blue holes are used for the base with the medium amount of screws and the base with the most screws uses all holes. The conical monopole antenna is a standard antenna design. The antenna, its dimensions and influences of CFRP onto such antennas are discussed in [9, 10]. The three aluminum bases with different holes are shown in Fig. 3 together with the brass cone.

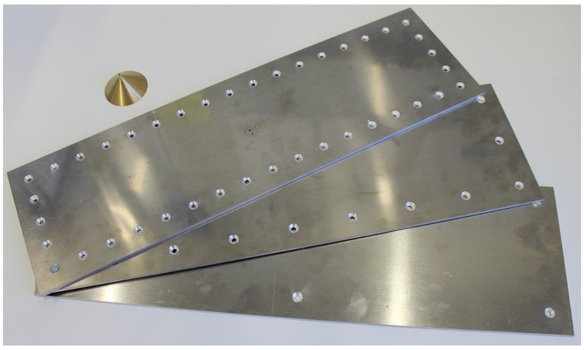

Figure 3: Exchangeable cavity bases and conical monopole antenna.

Electric contacting between cavity and exchangeable bases is straightforward for metal cavities. The electrically conductive bases are then directly screwed to the conductive cavity. For carbon fiber reinforced polymer (CFRP) cavities this is not so straightforward, as the conductive carbon fibers are buried under an insulating epoxy layer. For measurements in anechoic chambers metal cavities can be used instead of CFRP, as metals result in comparable antenna performance [10]. For drive test measurements this is not possible, as the car chassis can not simply be replaced. As CFRP are already used as chassis material in mass produced cars, the focus in this paper is therefore on CFRP cavities. A rectangular hole was cut into the cavity floor by water jet, as laser cutting is not suitable for CFRP. The holes placed along the cutout fit the ones in the bases, as is depicted in Fig. 4. Waterjet cutting caused delamination on some holes, but for the antenna performance this is of little interest, as these regions are covered by the aluminum bases anyway.

Two things are problematic in this exchangeable base design and require that prototypes are evaluated by measurement. Firstly, the exchangeable bases are placed on the CFRP's surface epoxy layer. Electrically, the bases are only (poorly) connected to the cavity's carbon fiber layers via the screws. Advanced contacting methods via the screws as in [11] are barely feasible for prototyping. Secondly, note that the distance between the screws is quite large compared to wavelength at higher frequencies. Connections can not easily be spaced as close, as it is possible for example on printed circuit boards, where vias are typically placed $\lambda/10$ apart.

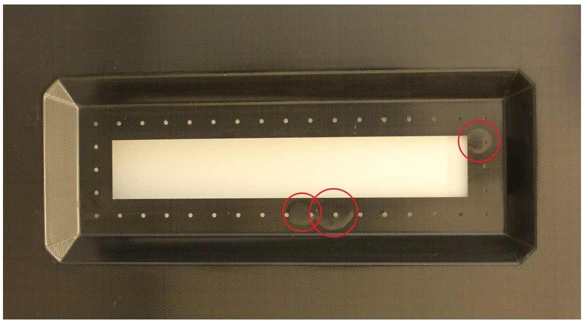

Figure 4: Cut bottom of a CFRP chassis antenna cavity module for exchangeable bases. Waterjet cutting caused delamination, which is circled red to increase visibility.

3 MEASUREMENT RESULTS

The directivity is a good indicator, whether the patterns on the different ground planes diverge over frequency. Fig. 5 shows the measured directivity up to 10 GHz. The directivity on the different bases is quite similar up to the frequencies where the monopole antenna is no longer useful inside the cavity. The normalized gain patterns at 5.9 GHz for dedicated short range communication are compared in Fig. 6 and Fig. 7. For the cut along the long side of the cavity the patterns on the different bases are quite similar (Fig. 6). On the cut along the short cavity side the patterns on the base with the fewest screws divert a few decibel from the other patterns. Results on the small aluminum ground plane imply, that the cone was slightly tilted during measurement. This is now improved with the exchangeable bases, as the ground planes are now properly mounted in the cavity. At lower frequencies, the radiation patterns are similar (these plots are not shown). The use of the exchangeable base with at least the medium number of screws is recommended.

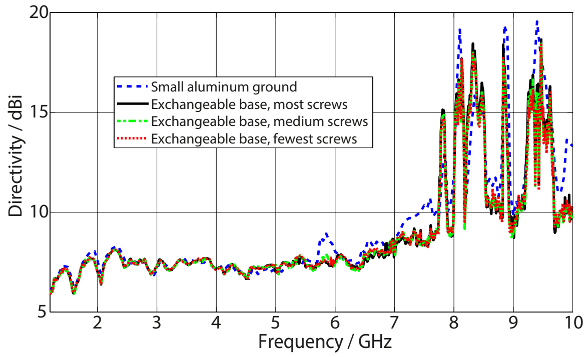

Figure 5: Directivity of a conical monopole antenna measured on exchangeable cavity bases with different number of screws.

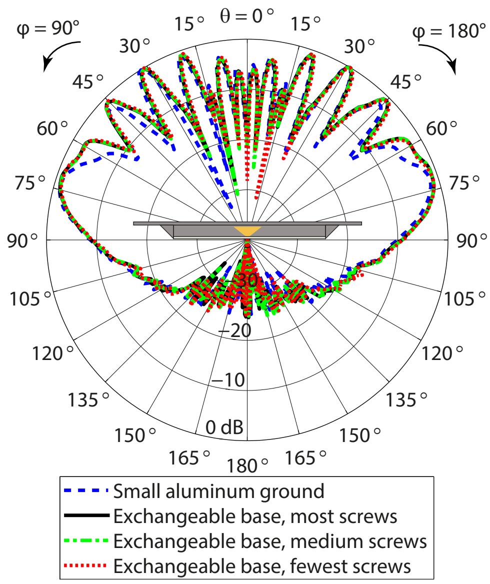

Figure 6: Normalized, measured gain patterns. Vertical cuts at 5.9 GHz, polar angle θ for azimuth $\varphi = 0°$.

4 CONCLUSION

Measuring multi-antenna systems or antennas at different positions inside a chassis antenna cavity requires holes for coaxial cables. The proper

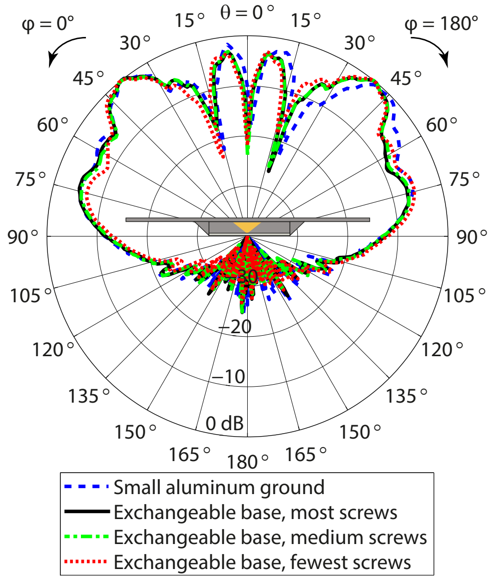

Figure 7: Normalized, measured gain patterns. Vertical cuts at 5.9 GHz, polar angle θ for azimuth $\varphi = 90°$.

contacting of carbon fiber reinforced polymer laminates is problematic, as the conductive carbon fibers are buried in epoxy. While it is possible to perform measurements inside anechoic chambers with metal cavities instead of CFRP cavities, the CFRP chassis of a car can not be replaced for drive tests.

Exchangeable cavity bases are proposed for prototyping of chassis antenna cavities. The bases are screwed to the cavity floor, which increases stability – as it is required for drive tests. Measurements in an anechoic chamber suggest, that the base with just six screws influences antenna performance and is not suitable for prototyping.

Acknowledgments

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