Material Induced Changes of Antenna Performance in Vehicular Applications

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***Abstract*—Recent advancements in production materials for cars replace well-known ground plane materials for vehicular antennas. Carbon-fiber composites (CFC's) replace steel as chassis material, which leads to reduced radiation efficiency. As the production processes of shark-fin antenna modules shift towards laser direct structuring (LDS), it is investigated, if antenna efficiency can be increased by the introduction of a LDS ground plane. Differences in antenna performance are presented on the example of simple LDS and wire monopole-antennas for $5.9\,$GHz (IEEE 801.11p, ITS G5). Gain, efficiency, return loss and the radiation patterns of an LDS design, a CFC and an aluminum ground plane are compared.**

I. Introduction

The state of the art of vehicular antenna design are shark-fin modules that are mounted at the rear center of the car roof. These modules include antennas for mobile telephony, car-to-car and car-to-infrastructure communication, positioning and entertainment services. Often several printed circuit boards (PCB's) are enclosed inside a radome [1].

A process called laser direct structuring (LDS) from LPKF Laser & Electronics AG allows the application of metal layers on three-dimensional plastic structures [2]. The design of shark-fin modules as molded interconnect devices (MID's) allows the antennas to be placed directly on the radome [3]. In cell phones LDS antennas are already widely used [4]. A log.-periodic antenna in LDS MID technology was presented in [5].

Carbon-fiber composites (CFC's) replace steel and aluminum as car body materials. CFC's consist of carbon-fibers molded together with an epoxy resin, they are light-weight and have high mechanical stability. CFC's are electric conductors. Their electrical properties depend on fiber-alignment, fiber-density and used matrix [6], [7].

In our recent work we have found that, for simple monopole antennas on circular ground planes and several CFC's, the substitution of an aluminum ground plane by a CFC does not significantly influence the radiation pattern and that the CFC reduces the efficiency of the monopole antenna.[8]

To mitigate the losses in the CFC ground plane, it might be feasible to include an LDS ground plane as part of LDS shark-fin modules. In this work differences in antenna performance on different ground plane materials are measured. Simple monopole antennas for $5.9\,$GHz are mounted onto ground planes made of aluminum, CFC and one from an LDS process.

The antennas and investigated ground plane materials are described in Section II. In Section III the measurement setup is explained. The measurement results are presented in Section IV. In Section V the presented work is summarized.

II. Manufactured monopole antennas

A wire monopole and an LDS monopole for $5.9\,$GHz are investigated on ground planes made from three different materials.

A. Investigated monopoles

An LDS design and a wire monopole are investigated.

The LDS design of the monopole is a $10 \times 2\,$mm rectangle placed on a $30 \times 20 \times 3\,$mm cuboid, made of Xantar LDS 3720, with the LDS-process. Xantar LDS 3720 from Mitsubishi Engineering has $\epsilon_r \approx 2.7$ and tan$\delta \approx 0.005$ [9]. The plastic is metalized with 6-8 μm Cu, 5-7 μm Ni and $0.1\,\mu$m Au. As the exact material properties from [9] were not available at the time of production, the resonance frequency is slightly shifted as depicted in Figure 4b.

As comparison a simple piece of straight wire is soldered to the inner conductor of an SMA connector. The wires are then cut to the appropriate length, such that the S_{11} resonance is at the desired frequency.

B. Investigated ground planes

All ground planes are quadratic with side lengths of $150\,$mm.

The ground plane denoted as *Al* is a $2\,$mm thick aluminum plate.

The second investigated ground plane is a $3\,$mm thick plate of XANTAR LDS 3720 with an LDS metalized top layer. The surface of the LDS ground plane is quite rough (according to the manufacturer 10-50 μm). The LDS ground plane was designed to be contacted with an SMA-flange. However, that prototype yielded questionable measurement results, either due to poor contacting between the four flange screws and the LDS ground plane with conductive epoxy, or due to insufficient shielding of the inner conductor by only four screws. Therefore, measurement results from a second prototype, where the outer conductor of a semi-rigid coaxial cable is soldered directly to the LDS ground plane, are presented in this paper. The assembled LDS antenna prototype is depicted in Figure 1.

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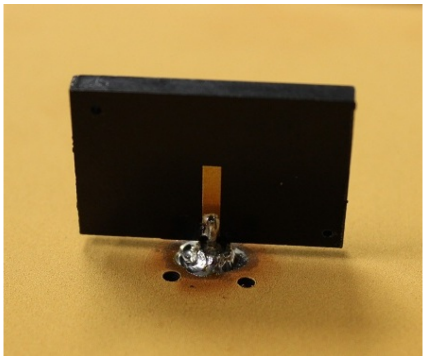


Fig. 1: Monopole antenna in MID technology. The outer conductor of a semi-rigid coaxial cable is soldered to the conductive LDS-layer of the ground plane. The inner conductor of the coaxial cable is soldered to the LDS monopole on the plastic carrier. The four holes designed for an SMA-flange remain unused.

Simulations of the LDS monopole on the LDS ground plane were performed in Ansoft HFSS. Metal layers are simulated as copper and Xantar LDS 3720 is modeled with the values from [9].

The third ground plane material is a 2.26 mm thick CFC plate. The CFC consists of unidirectional filaments with fiber snippets in random alignment on top. The CFC investigated in this paper is the same one as CFC2 in [8]. The CFC ground plane was contacted by screwing an SMA-connector to threads in the plate. A wire monopole mounted to the CFC ground plane is depicted in Figure 2.

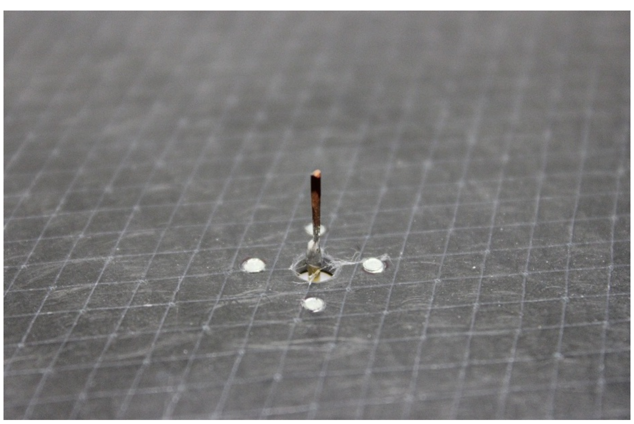


Fig. 2: Wire monopole antenna for 5.9 GHz on the CFC ground plane.

III. Measurement Setup

Near-field measurements were performed inside the institutes anechoic measurements chamber. Results presented in Section IV were obtained via a near-to-far-field transformation. Antennas under test (AUT's) were mounted on a pillar made of Rohacell IG31F. An NSI-RF-SG137 horn antenna was used for gain calibration. All AUT's were aligned such that the monopole points in z-direction ($\theta = 0$) and an edge of the square ground plane points towards x-direction ($\varphi = 0$). The coordinate system and the measurement setup are depicted in Figure 3.

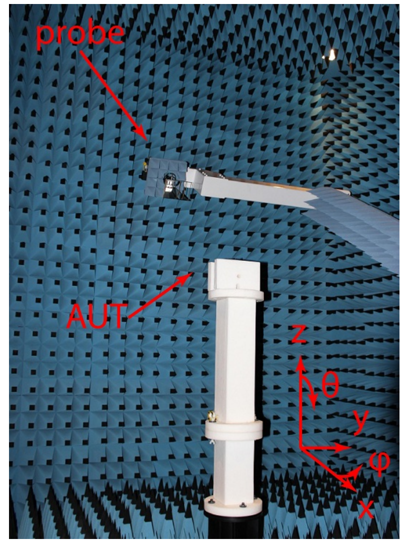


Fig. 3: Antenna under test (AUT) and coordinate system inside the near-field anechoic chamber.

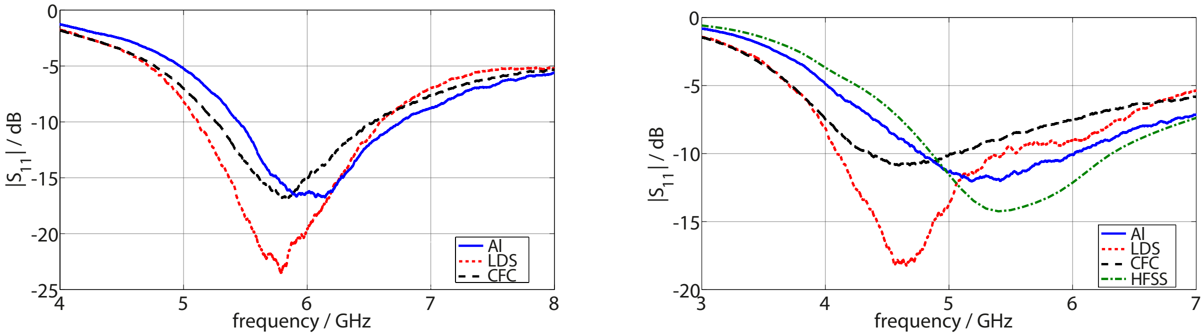
IV. Measurement Results

Return loss measurements of the monopole antennas are shown in Figure 4. The return loss of the wire monopoles is depicted in Figure 4a. The length of the wire monopole antennas were modified for each ground plane material, to achieve the desired resonance frequency. As mentioned in Section II, the LDS antenna was designed without knowledge of the exact properties of the carrier material from [9]. For the LDS monopole the resonance frequency is shifted towards lower frequencies for both the CFC and the LDS ground planes, as depicted in in Figure 4b. However, the return loss at 5.9 GHz is good enough for all ground plane materials to get meaningful results at this frequency.

Radiation patterns that show the dependency on polar angle θ for the different ground planes are depicted in Figure 5. The measurement results for the wire monopole are shown in Figure 5a and the results for the LDS monopole in Figure 5b. Both monopoles show the expected radiation pattern. Neither the LDS, nor the CFC ground plane cause significant changes in the radiation pattern.

Radiation patterns with dependency on azimuthal angle φ for $\theta = 60°$ are shown in Figure 6. For the wire monopole no significant deviations due to the used ground plane material are visible in Figure 6a. The flat monopole of the LDS design and the presence of the PC/ABS block are expected to distort the radiation pattern, the extent of which is visible in Figure 6b. The used CFC does not significantly influence the radiation pattern of the investigated antennas.

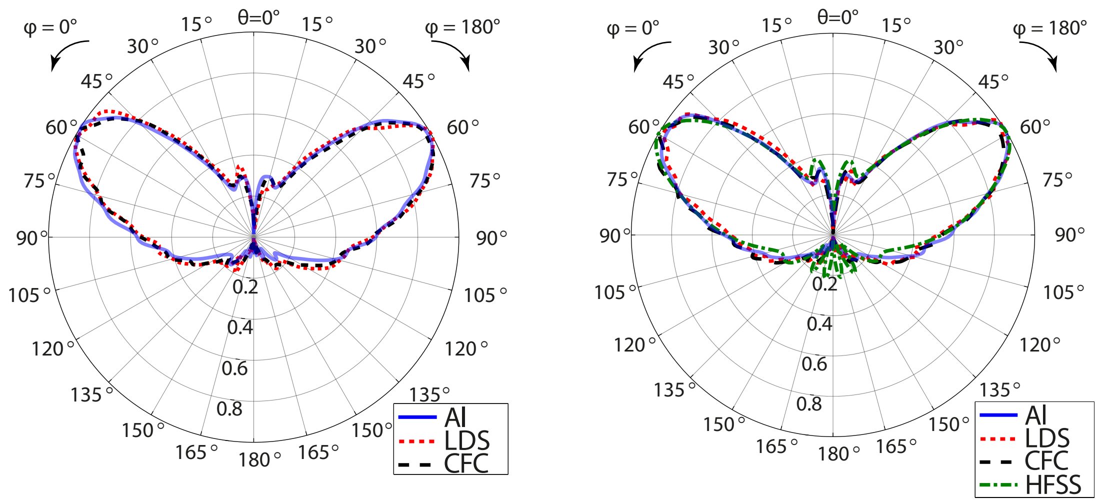
Measured antenna properties for the different ground plane materials are summarized in Table I for the wire monopole and for the LDS monopole in Table II. The best return loss, the 10 dB bandwidth, the bandwidth relative to that of the wire monopole on the aluminum ground plane, the



(a) Return loss of wire monopoles

(b) Return loss of LDS monopoles

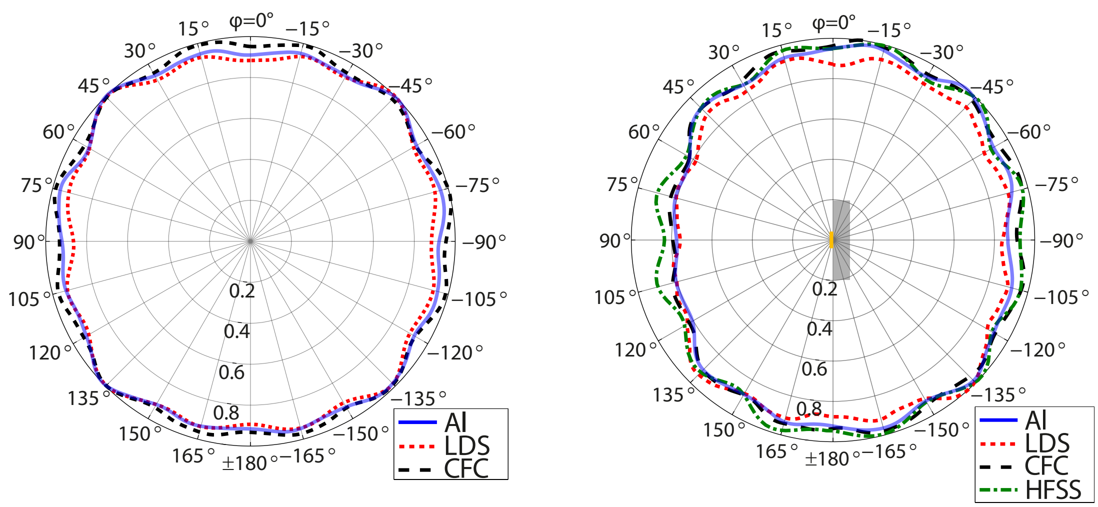
Fig. 4: Measured return loss of the monopole antennas with different ground plane materials.



(a) Radiation pattern of wire monopoles

(b) Radiation pattern of LDS monopoles

Fig. 5: Radiation patterns of wire and LDS monopoles with different ground plane materials. Dependence of polar angle θ at azimuthal angle $\varphi = 0°$ (left side) and $\varphi = 180°$ (right side).



(a) Radiation pattern of wire monopoles

(b) Radiation pattern of LDS monopoles

Fig. 6: Radiation patterns of wire and LDS monopoles with different ground plane materials. Dependence of azimuthal angle φ at polar angle $\theta = 60°$.

maximum gain and the radiation efficiency relative to that of the wire monopole on Al are shown. As expected the radiation efficiency with a CFC ground plane is significantly lower than with an aluminum ground plane. The radiation efficiency with a wire monopole on a CFC ground plane is similar to that found in [8].

The efficiency of monopole antennas on CFC ground planes could be improved by a superposed metal ground plane. Such a ground plane could be designed and manufactured as part of an MID antenna.

TABLE I: Measured antenna properties for different ground plane materials with a wire monopole.

wire monopole	Al	MID	CFC
best return loss [dB]	16.6	23.4	16.8
10 dB bandwidth [GHz]	1.49	1.48	1.45
relative 10 dB BW [%]	100.0	98.0	97.3
maximum gain [dBi]	5.3	5.3	4.2
relative efficiency [%]	100.0	95.9	80.5

TABLE II: Measured antenna properties for the LDS monopole with different ground plane materials.

LDS monopole	Al	MID	CFC
best return loss [dB]	12.0	18.2	10.9
10 dB bandwidth [GHz]	1.25	1.44	0.68
relative 10 dB BW [%]	83.9	96.6	45.6
maximum gain [dBi]	5.0	5.2	3.8
relative efficiency [%]	89.1	87.4	70.4

V. Conclusion

The performances of a wire and a MID monopole antenna were measured on rectangular ground planes made from aluminum, CFC and with the LDS process. Measured radiation patterns, radiation efficiency, gain and return loss of a MID ground plane were compared to those of an aluminum and a CFC ground plane.

Compared to an aluminum ground plane the investigated CFC and LDS ground planes cause no significant change in the radiation pattern of the monopole antenna. Use of a monopole antenna on the investigated CFC ground plane reduces the efficiency of the antenna by about 20% compared to operation on an aluminum ground plane.

Based on the presented evidence we suspect that the radiation efficiency of a monopole antenna on CFC can be improved by the introduction of a superposed LDS ground plane.

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 Conference on Antennas and Propagation in Wireless Communications (APWC), August 2014

[2] N. Heininger, W. John and H. J. Boßler, *Manufacturing of molded interconnect devices from prototyping to mass production with laser direct structuring*, International Congress MID, 2004

[3] A. Friedrich, B. Geck, O. Klemp and H. Kellermann, *On the Design of a 3D LTE Antenna for Automotive Applications based on MID Technology*, European Microwave Conference (EuMC), October 2013

[4] F. Sonnerat, R. Pilard, F. Gianesello, D. Gloria, F. Le Pennec, C. Person, A. Cihangir, F. Ferrero, C. Luxey, and P. Brachat. *Wideband LDS antenna using two radiating elements*, Loughborough Antennas and Propagation Conference (LAPC), November 2012

[5] C. Orlob, Q. H. Dao and D. Kornek, *Dual-Polarized Log.-Periodic Antenna on a Conical MID Substrate*, European Conference on Antennas and Propagation (EUCAP), April 2011

[6] H. C. Kim and S. K. See, *Electrical properties of unidirectional carbon-epoxy composites in wide frequency band*, Journal of Physics D: Applied Physics 23, 1990.

[7] 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, Vol. 116, 2011.

[8] 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 Conference on Antennas and Propagation in Wireless Communications (APWC), August 2014

[9] Q.H. Dao, A. Friedrich and B. Geck, *Characterization of Electromagnetic Properties of MID Materials for High Frequency Applications up to 67 GHz*, Advanced Materials Research. Vol. 1038, 2014