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On the Design of a 3D LTE Antenna for Automotive Applications based on MID Technology

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Abstract—**This paper presents the design of a long-term evolution (LTE) antenna and its integration on the 3D surface of the mounting compartment of an automotive roof-top antenna, using molded interconnect device (MID) technology. In the first step the design of the planar LTE antenna is shown. This antenna provides an input matching better than 10 dB in the desired frequency band and exhibits an omnidirectional radiation characteristic in the horizontal plane. Subsequently, this antenna is bent on the surface of a roof antenna housing. The effects of geometrical mapping of the planar antenna structure to the 3D surface in terms of input matching and radiation characteristics are analyzed. Based on these findings, a conformal and optimized two antenna system is introduced and discussed. A prototype realized by MID laser direct structuring (LDS) is presented and the measured antenna performance is compared to simulation results. An excellent agreement between measured and simulated results is observed. Finally, the prototype meets the specification requirements.**

Keywords—MID; LDS; antennas; automotive application; LTE

I. INTRODUCTION

Future vehicles tend to increase their capabilities to connect wirelessly to a large variety of services. The connected vehicles vision aims at an efficient utilization of resources in wireless communications to provide advanced functionality in infotainment, traffic efficiency and safety to the driver. In order to meet the requirements for different applications in broadcasting and telematics, automotive on-board equipment has to be integrated for an ever increasing number of wireless services [1]. Typically, automotive on-board antennas like integrated on-glass antennas, rod antennas and integrated roof-top antennas are used in order to cover the entire number of communication standards. The roof-top antenna module typically provides functionality for different broadcasting and telecommunications services. Those include antennas for cellular communications and Global Navigation Satellite Services (e. g. Global Positioning System (GPS)) as well as for satellite radio services (e.g., US Satellite Digital Audio Radio Systems (SDARS)). Generally, the roof-top antenna compartment is enclosed by a dielectric housing, as depicted in Fig. 1, that shall protect from environmental influence. Since the roof-top compartment is subject to aesthetic design considerations, its overall size remains constant even though

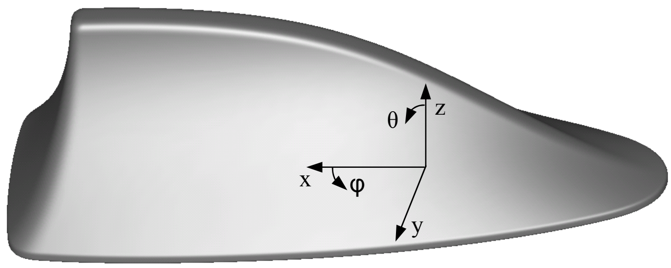

Fig. 1 Roof antenna housing and definition of coordinate system

the number of individual antennas increases since emerging telecommunication standards need to be included. As such, mutual coupling between antenna elements inside of the antenna compartment may lead to degraded performance metrics of the related communication services. In order to provide improved service delivery and increased link robustness, cellular networks like the 4G LTE are of prime interest to the automotive industry. Since multiple antenna technology is being used in LTE for improved network scalability, an additional number of antennas have to be integrated. Conventional antenna manufacturing technology is based on 2D printed circuit board or patch antenna elements that are mounted to the base plate of the roof-top antenna compartment. This technology leads to an inefficient utilization of available space resulting in low antenna efficiency, limited return loss esp. at UHF frequencies and increased mutual coupling between individual antennas [2]. In addition, dielectric loading and parasitic elements in the mounting compartment may additionally lead to a further deterioration of antenna performance [3]. In order to increase the space utilization of the roof-top antenna to improve antenna performance metrics, this investigation focuses on the direct implementation of antenna functions on top of the surface of the enclosed integration volume. The MID antenna design therefore enables a better utilization of available mounting space which is an important prerequisite for improved antenna decoupling in LTE multiple-antenna technology.

The laser direct structuring technology LDS is a MID manufacturing technique which supports rapid prototyping use cases [4]. LDS requires special plastics doped with an organic metal complex [5]. The surfaces to be metalized are subject to electroplating after being activated with a laser. This provides

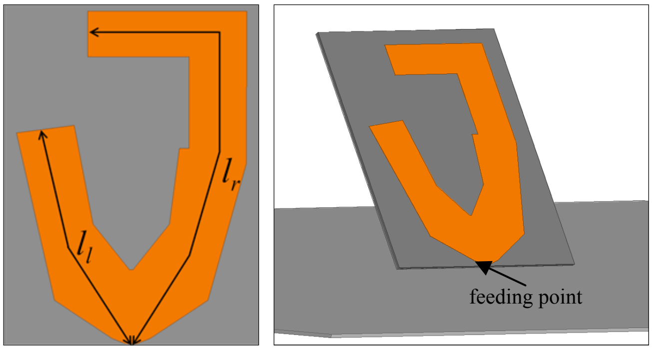

Fig. 2 Planar LTE antenna

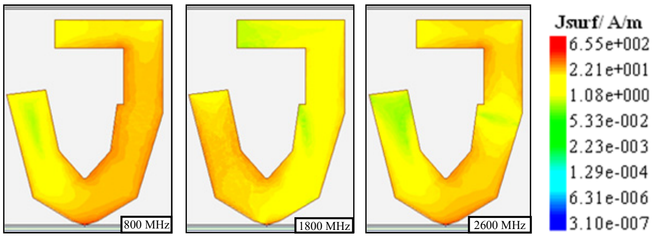

Fig. 3 Current distribution in the LTE band

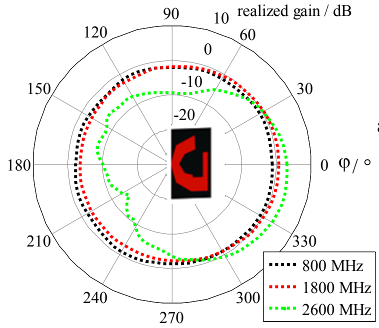

Fig. 4 Radiation characteristics (RC)

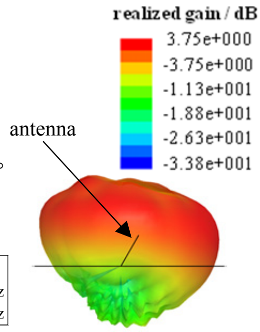

Fig. 5 RC at 2600 MHz

the opportunity to integrate circuits and antennas onto plastic surfaces and to thus increase the space efficiency. The proposed LTE antenna system is targeted to operate at LTE 800 MHz (791-862 MHz), 1800 MHz (1710-1880 MHz) and 2600 MHz (2520-2690 MHz). An input matching better than 10 dB at a 50 Ω load and inter-element antenna isolation better than 12 dB shall be obtained. In order to provide good coverage in terrestrial LTE communications, omnidirectional antenna characteristics shall be obtained in the horizontal plane.

II. Analysis of the Planar Antenna Structure

The antenna prototype is based on a planar modified broadband bow tie antenna over a metallic ground plane (1 × 1 m) structured on a LDS capable MID substrate material (Fig. 2). According to the conditions in the integration compartment the antenna substrate is inclined to the ground plane. The coaxial feeding point is located in the middle of the lower edge.

A. Description of the functional principle

The frequency range of a bow-tie antenna is strongly influenced by the arm length l_r and l_l. For operating in the LTE band its length l_l has been chosen to 48 mm obtaining a broadband input matching better than 10 dB from 1500 MHz up to 3500 MHz. The radiation characteristic is expected to be omnidirectional in the horizontal plane. For the LTE 800 MHz band the electrical length of the antenna needs to be increased. Therefore a bent resonant arm is added and the metallization at the center of the bow tie antenna is removed. The current distribution at the different LTE frequencies is shown in Fig 3. At 800 MHz the main current is in the right additional arm, as expected. At 1800 MHz the resonating edges are the outer edges of the left arm and at 2600 MHz band the third harmonic of the 800 MHz resonance constructively interferes with the broadband characteristic of the bow tie structure.

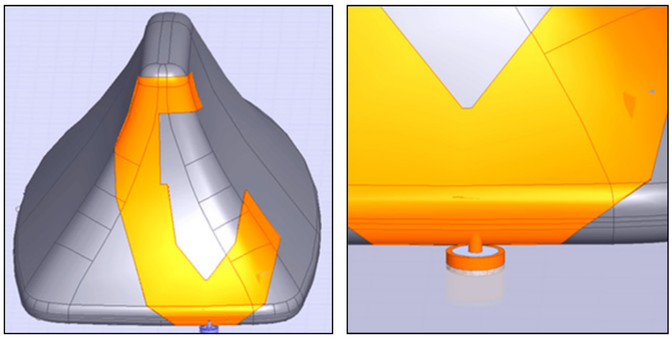

Fig. 6 Antenna and feeding point on the back side of the plastic housing

B. Simulated results for planar antenna

The simulated results of the planar antenna shown in Fig. 2 are discussed in the following. All simulations were done with Ansys HFSS 14.0. Fig. 7 shows the input matching of this antenna from 0.5 GHz up to 3.5 GHz. The input matching is better than 10 dB in the desired LTE band. Especially from 1600 MHz up to 3500 MHz an input matching of almost 15 dB can be achieved. Fig. 4 shows the radiation characteristic in the horizontal plane. As expected, an omnidirectional characteristic is achieved at 800 MHz and 1800 MHz. At 2600 MHz the antenna pattern is rotated due to the inclined antenna structure. This reduces the realized gain in the horizontal plane. (Fig. 4 and Fig. 5)

III. Analysis of the Bent LTE Antenna

The plastic housing of the roof antenna module used is shown in Fig. 1. The planar antenna shown in Fig. 2 is bent on the surface of the plastic housing and the changes in input matching and radiation characteristics are evaluated. In the first design step only one antenna is bent onto the surface in different positions. Afterwards two optimized antennas bent on the plastic housing are evaluated regarding their performance and their impact on each other.

A. Simulated results for antenna on back housing

Fig. 6 shows the antenna bent on the back of the plastic housing. The antenna arms are bent around the edge of the sidewalls of the housing. This causes a sharp bend of nearly 90°. The coaxial feeding point is on the lower edge of the housing as shown in Fig. 6. For the simulation a coaxial line is routed straight through the ground plane and modeled as waveguide port. Fig. 7 shows the input matching of this antenna against the planar antenna from section II. The input

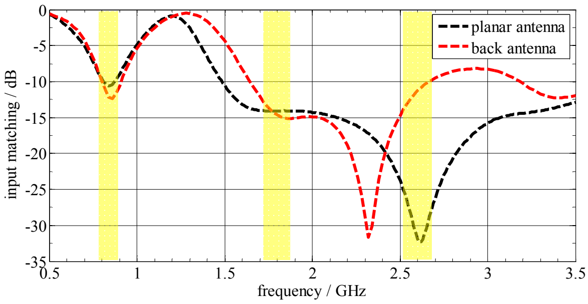

Fig. 7 Input matching of the planar prototype and the antenna on the back side

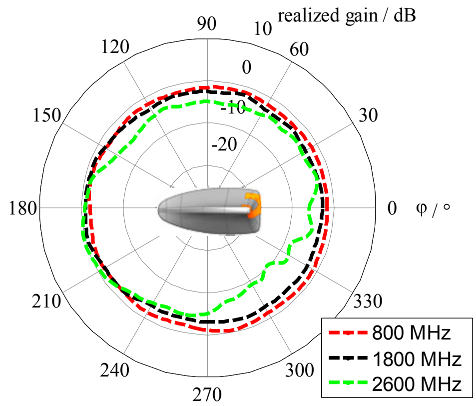

Fig. 8 Radiation characteristic at LTE frequencies

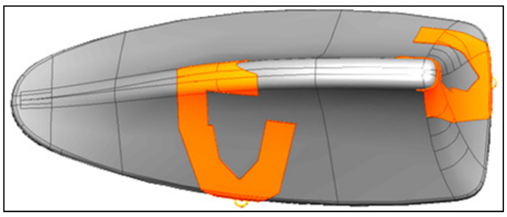

Fig. 9 Two antenna system on plastic housing

matching of both antennas is nearly the same in the frequency range from 790-890 MHz. From 1500-3500 MHz a shift of the resonance frequency from 2600 MHz down to 2300 MHz is caused by the bending operation. Furthermore this resonance is narrower than for the planar antenna. The shift of resonance is caused by the changed length due to the bending operation. The sharp bend also causes a decrease of the width of both arms. Thus the resulting resonance becomes narrower. Fig. 8 shows the radiation characteristics at 800 MHz, 1800 MHz and 2600 MHz in the horizontal plane. In the 800 MHz and 1800 MHz bands the characteristic is omnidirectional in horizontal plane, as required. The characteristic at 2600 MHz is similar to that of the planar antenna. Caused by the rotation of the antenna by 30°, the radiation pattern is rotated accordingly as can be seen in Fig. 8 for the planar antenna. This causes a reduction of realized gain in the horizontal plane for the range of $\varphi = 270°$ up to $\varphi = 360°$.

B. *Simulated results of the two antenna LTE system*

In the next step, two antennas are integrated onto the plastic housing as shown in Fig 9. This placement turns out to be the optimum concerning the single antenna performance and the isolation between both antennas. The simulated input matching for both antennas and the isolation are shown in Fig. 10 and

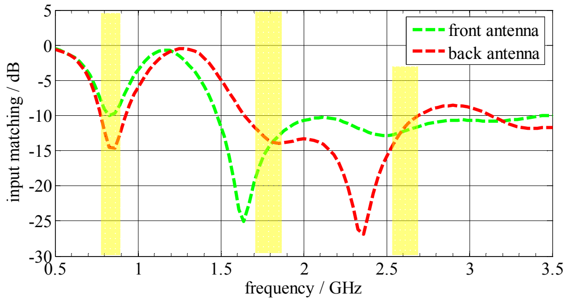

Fig. 10 Input matching for the LTE two antenna system

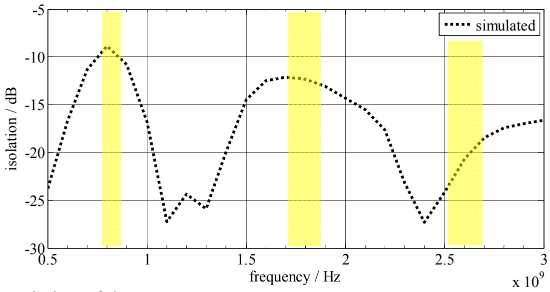

Fig. 11 Isolation of the LTE two antenna system

Fig. 12 Realized two-antenna system with feeding structure

Fig. 11, respectively. Again, the back antenna exhibits nearly the same input matching as the planar one. The front antenna has a longer right arm and a larger top capacitance on the left arm. Both effects change the resonance frequency from 2600 MHz (planar antenna) down to 1700 MHz for the bent version. Nevertheless, the required input matching in the LTE band is achieved. The isolation between the two antennas is always larger than 12 dB except in the 800 MHz band, where 9 dB are achieved. The simulated radiation characteristics are depicted as dashed lines in Fig. 15 for the front antenna and in Fig. 16 for the back antenna.

IV. ANALYSIS OF THE REALIZED TWO ANTENNA SYSTEM

The two-element LTE antenna system discussed in the last section is realized on a thin walled roof antenna housing shown in Fig 12. The LDS material used is Vectra E840i LDS, a liquid crystal polymer, suitable for thin walled injection molding. The complex permittivity of this material is determined with a circular cylindrical cavity [6] as $\varepsilon_r = 4.2$ and $\tan\ \delta = 0.0027$ at 2.69 GHz. The metallization in the LDS process is done with copper and a nickel/gold covering to reduce oxidation and metallization losses. For the measurements the feeding point of the antenna has to be routed inside the housing and needs to be geometrically matched to a connector. Therefore a stripline is routed from the feeding point used for simulations straight under the

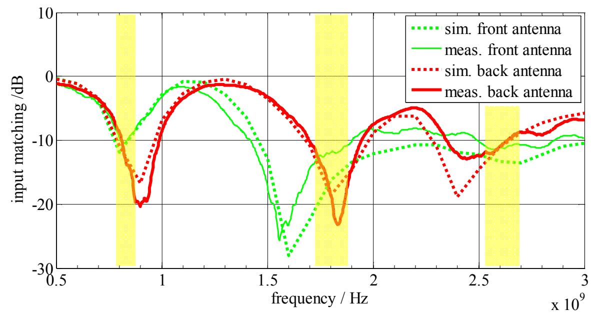

Fig. 13 Input matching of two antenna system

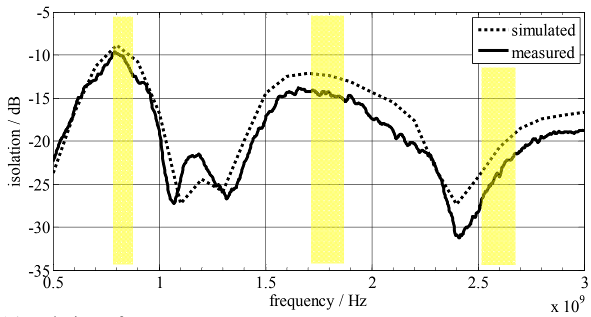

Fig. 14 Isolation of two antenna system

housing. On the inside edge a SMA connector is installed as shown in Fig. 12. One small-sized pair of screws fixes the connector to the edge of the plastic housing and the other pair connects the whole structure with the ground plane. As in the simulations the ground plane is a 1 m × 1 m aluminium plate with 2 mm thickness. To compare measured and simulated results the simulations shown in the following are done with the SMA connector previously described.

A. Measured results of the two antenna LTE system

In the following, the measurement results are compared to those obtained with Ansys HFSS 14.0. First, the scattering parameters of both antennas are investigated. The results for the input matching and the isolation are presented in Fig. 13 and Fig 14. The measured results are plotted with dotted lines and the simulated results with continuous lines. The measured and the simulated results show a good agreement. They indicate an input matching better than 10 dB in the desired LTE band. The radiation properties of the antennas are measured in an anechoic chamber. The results for 800 MHz 1800 MHz and 2600 MHz in the horizontal plane are shown in Fig. 15 and Fig. 16. The measured and simulated results show an adequate agreement.

V. Conclusion

In this paper a LTE antenna design on the plastic housing of an automotive roof-top antenna was presented. It was shown that the conformal mapping of the planar prototype antenna structure to the three-dimensional surface of the housing exhibits a minor influence to the antenna characteristics. In the next step a LTE two antenna system based on the presented planar antenna was evaluated. The single antennas achieve an input matching better than 10 dB in the desired LTE band and have an omnidirectional radiation characteristic in the horizontal plane. The isolation between both antennas is

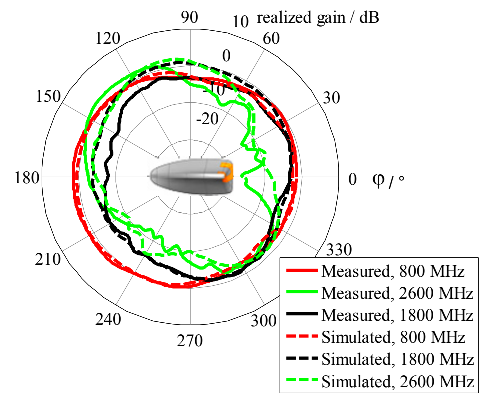

Fig. 15 Radiation characteristic at LTE frequencies for front antenna

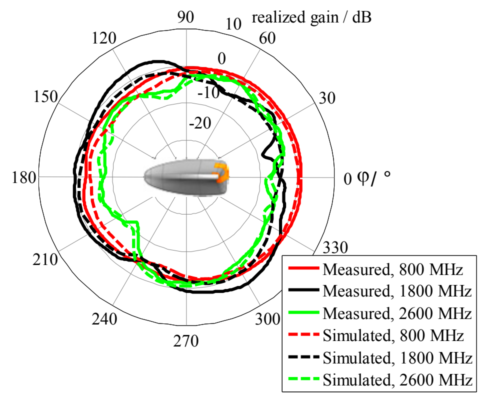

Fig. 16 Radiation characteristic at LTE frequencies for back antenna

always better than 12 dB, except in the 800 MHz band, where 9 dB are achieved due to the wavelength in relation to the size of the housing. The realization of this two antenna system on an LDS capable plastic housing was presented and discussed. The measured results exhibit a very good agreement with full-wave simulations. It was shown that the aforementioned requirements on the LTE antenna can be very well met with MID technology.

References

[1] E. Gschwendtner and W.Wiesbeck, "Ultra-broadband car antennas for communications and navigation applications," *IEEE Trans. Antennas Propag.*, vol. 51, no. 8, pp. 2020–2027, Aug. 2003.

[2] A. Thiel, O. Klemp A. Paier, L. Bernado, J, Karedal, A. Kwoczek: „ In-situ vehicular antenna integration and design aspects for vehicle-to-vehicle communications ", 2010 Proceedings of the 4th European Conference on Antennas and Propagation (EuCAP), pp. 1 -5, April 2010.

[3] O. Klemp: "Performance considerations for automotive antenna equipment in vehicle-to-vehicle communications", 2010 URSI International Symposium on Electromagnetic Theory (EMTS), pp. 934 – 937, Aug. 2010.

[4] Forschungsvereinigung Räumliche Elektronische Baugruppen 3-D MID e.V., "Technologie 3D-MID – Räumliche elektronische Baugruppen", München: Carl Hanser Verlag, 2004.

[5] R. Schlueter, B. Roesener, J. Kickelhain, and G. Naundorf, "Completely additive laser-based process for the production of 3D MIDs, The LPKF LDS process," in *5th International Congress Molded Interconnect Devices*, Erlangen, Germany, 2002.

[6] S. Zinal and G. Boeck, "Complex permittivity measurements using TE_{11p} modes in circular cylindrical cavities," *IEEE Trans. Microwave Theory Tech.*, vol. 53, pp. 1870–1874, June 2005.