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# 24 GHz Dielectric Filled Waveguide Fed Horn Antenna Using 3D-LDS MID Technology

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**Abstract**—This paper presents the evaluation of dielectric tapered horn antennas that are fed by planar radio frequency (RF) transmission line to dielectric filled waveguide transitions. The antennas are developed to be efficiently manufactured with the laser direct structuring (LDS) method that allows for a 3d metalization of plastic surfaces. In doing so the flexibility of the antenna design process is increased. Furthermore the antennas can be directly combined with a circuitry if required. First of all, a fundamental evaluation is done by means of two different transitions from typical RF transmission lines to a rectangular dielectric filled waveguide at 24 GHz. Based on these findings a test antenna is designed and subsequently manufactured with the LDS method. To evaluate the manufacturability with the LDS method in general and additionally prove the concept, the configuration of this test antenna is kept relatively simple. The prototype is characterized in an anechoic chamber and the results are discussed. In the next step an additional example design that is based on an typical dielectric antenna is discussed. To conclude, the results obtained are summarized and discussed with respect to a use for the development of RF applications.

## I. INTRODUCTION

Modern radio frequency (RF) applications have to meet different, often contradictory, demands concerning their mechanical as well as electrical functionality. The ever decreasing installation spaces are contrary to the increasing number of radio services to be integrated. For the antenna development more flexibility in design process is one way of helping to meet these requirements. Summarized under the term molded interconnect device (MID) technology, different manufacturing methods that allow for a selective metalization of nearly arbitrary shaped plastic surfaces are available. 2shot, aerosol jet printing, to only name but a few: The laser direct structuring technology (LDS) is one flexible and reliable method that has been established as the preferred method for manufacturing MIDs. In this case an injection molded plastic part that is doped with a mixed metal oxide is structured with a laser. The laser activates the metal oxide and causes a micro rough surface that allows for a selective deposition of copper in an electroless copper bath, while at the same time contributes to a strong bonding between the substrate and the metal layer. Similar to conventional PCB technology, different surface finishes such as ENIG (Electroless Nickel / Immersion Gold), ENEPIG (Electroless Nickel / Electroless Palladium / Immer-

sion Gold), Immersion Silver and others can be deposited with electroless plating processes. Alternatively, a variety of metal finishes can be applied by electroplating processes. Fig. 1 shows the different fabrication steps described. Besides several applications in DC range, the LDS method has already been used in large scale productions of antennas for smart mobile devices such as smartphones, tablets and laptops. By metalizing the surface of the housing of a device only a small design scope gained out of the three dimensional manufacturing is used. The possibility of an arbitrary shaped surface combined with its metalization can additionally be used to optimize specific antenna characteristics, like it is done for a typically planar patch antenna in [1]. Another type of antenna that could be enhanced by using a 3d manufacturing method are dielectric or horn antennas that are fed by a dielectric filled waveguide. These antennas can be used in a sensor application, for example. The LDS capable plastic parts are typically fabricated in an injection molded process so that the shape of the dielectric antenna is only limited by the respective design rules. Furthermore the selective metalization of these dielectric surfaces can be used to influence the antenna. In addition to the antenna optimization itself the combination of circuit elements and the waveguide fed antenna can be manufactured as one part. In that way an RF circuit can be interconnected directly to a dielectric filled waveguide that feeds the dielectric or dielectric filled/coated antenna using a transition from the RF transmission line to dielectric filled waveguide. This contribution is intended to give a brief overview on some possibilities to design this waveguide fed antennas using the 3d LDS fabrication at 24 GHz.

This paper is structured as follows. Section II starts with a simulation based evaluation of transitions from microstrip line (MSL) and grounded coplanar waveguide (G-CPW) to a rectangular waveguide. Based on this in the next section a prototype structure is developed. A grounded coplanar waveguide to rectangular waveguide, exciting the fundamental mode  $H_{10}$ , is used to feed a simple dielectric horn that is tapered in only one dimension. A prototype antenna that is realized with the LDS method is characterized and the results are discussed in section III-B. Considering these results an additional example antenna is designed and evaluated to show how the 3d LDS



Fig. 1. Different fabrication steps of the LDS process - Injection molded, structured, metalized and assembled part

method can be used to fabricate a typical dielectric antenna. In the last section the conclusion is drawn.

## II. DIELECTRIC FILLED WAVEGUIDES USING LDS TECHNOLOGY

In addition to the optimization of antennas by using 3d metalized plastic parts, the efficiency of the fabrication process itself can be enhanced by combining circuitry and antennas in one part. In case of a dielectric filled waveguide fed antenna that should be combined with an RF circuit a transition from the transmission line, which is used in the circuit part, to the waveguide has to be made. To achieve the reduction of complexity intended this transition has to be efficiently manufacturable with the LDS method. Ideally the transition should be realized only with surface metalization and without additional pins or slots. Due to the fact that the thickness of the plastic part of the RF circuit will be different from that of the dielectric filled rectangular waveguide a mechanical transition between both has to be made additionally.

All simulations in the following are carried out using Ansoft HFSS Version 14.0.1. The substrate material used is a polycarbonate (MEP Xantar LDS 3730) with a permittivity of  $\epsilon_r = 2.9$  and a loss tangent of about  $\tan \delta = 0.005$ . This material is designed for the use of the LDS technology by offering good plating ability, high adhesion and mechanical robustness. Due to its property profile, Xantar LDS 3730 has been widely used for LDS MID applications in automotive and consumer electronic industry. The metalization is modeled using sheets with the conductivity of LDS copper considering the surface roughness with the Huray surface roughness model implemented in HFSS. Fig.2 shows the simulation model of a possible transition from grounded coplanar waveguide and microstrip line to a 24 GHz rectangular waveguide. The mechanical transition is done in one step and without tapering of the plastic part. The excitation of the fundamental mode in the waveguide is done with the inner conductor of the CPW/MSL that is tapered and connected to the boundary surface of the waveguide. These surfaces are additionally connected to the ground conductor of the transmission lines. By varying the slot width on the left and right side of the

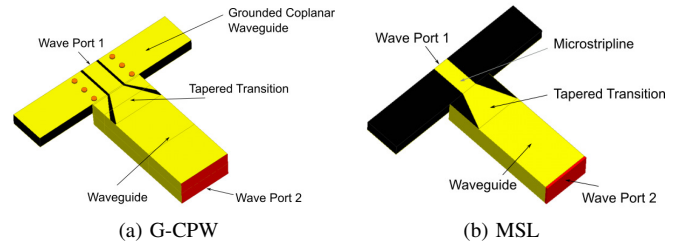


Fig. 2. Model of the different transitions to waveguide

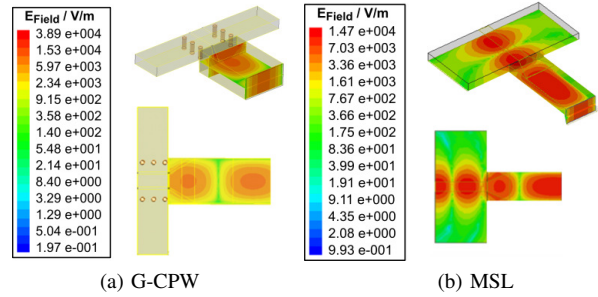


Fig. 3. Simulated E-field for the different transitions to waveguide

taper and the width and length of the taper, the input reflection coefficient can be tuned. This method is similar to transitions used for substrate integrated waveguides (SIW), for example in [4]. In the following simulations the G-CPW/MSL on one side and the rectangular waveguide on the other side are excited by a wave port. (Fig. 2)

As it can be seen from the electrical field in Fig.3 in the waveguide, the respective fundamental modes on both structures are excited. Considering the transmission and input reflection coefficient in Fig.4, it can be seen that for this structure with a length of about  $4 \lambda_{diel}$  the simulated attenuation is about 2 dB (MSL) and 2.5 dB (G-CPW) at 24 GHz. For the MSL the transmission coefficient is slightly increasing to higher frequencies. This is on one hand due to the decreasing input reflection. On the other hand a very small part of the input power is radiated due to the slight mismatch at 23 GHz causing additional losses. The input matching is better than 11 dB at 24 GHz for both configurations. The transitions shown allow the feeding of a waveguide directly from a circuit board.

## III. DIELECTRIC FILLED WAVEGUIDE FED ANTENNA

In the next step the dielectric filled waveguide at 24 GHz will be used to feed a dielectric horn antenna. A prototype antenna of this structure is realized to verify the concept and evaluate the possibilities of the LDS manufacturing technology for this kind of application. Since up to now, the LDS method has only been used for applications up to 6 GHz one main aim of this realization is to evaluate the fabrication of this structures in terms of the frequency range. Not only the influences of the relatively high surface roughness but also the tolerances and the achievable resolution during the fabrication process have to be considered. Therefore, in the first step the

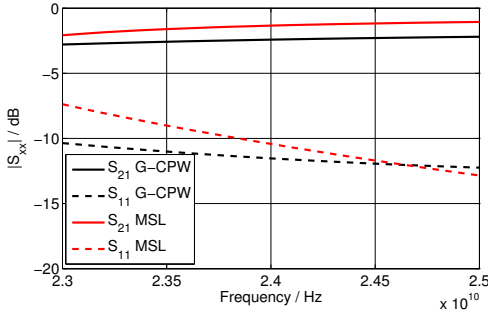


Fig. 4. Simulated S-Parameter of the different transitions to rectangular waveguide

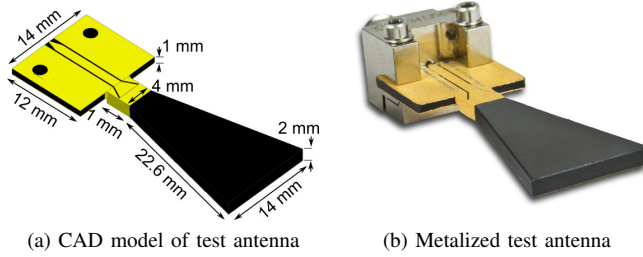


Fig. 5. Realized prototype dielectric horn antenna

design is kept mechanical very simple and uses only a few possibilities that are gained from 3d LDS MIDs.

#### A. Test Antenna Design

Fig. 5a shows the CAD model of the test antenna design. The test structure consists of a G-CPW part that represents the area where later a circuit could be placed on. The dielectric filled waveguide that follows feeds the dielectric tapered horn [2]. The horn is tapered only in one dimension for this prototype that is similar to planar SIW structures. For this first evaluation a realization of an injection molded part was not possible. This has to be considered when evaluating the functionality of the antenna in the following. Since the test structure is mainly intended to prove the concept and the LDS fabrication process at 24 GHz, the comparison between measurements and simulation is sufficient to achieve this. For a concrete antenna application with an injection molded part and its selective 3d metalization, the full 3d design space can be used and e.g. a tapering in the vertical direction could be realized.

Fig. 5b shows the metalized test structure. The plastic part is milled from an injection molded plastic plate with a height of 2 mm. The material used is the XantarLDS 3730. The metalization of these test antennas is the standard LDS metalization (copper/nickel/gold). Compared to plain metal walls of a waveguide the roughness of the LDS metalization is considerably higher. This will cause conductor losses in addition to the material losses in the substrate. The surface roughness can be influenced by the laser parameter in the laser structuring process. In consequence this has an impact

on the adhesion strength of the copper so that in turn a balance between both has to be found in order to guarantee a sufficient reliability and minimal RF losses. Especially for RF applications in higher frequency ranges where sensitive RF-components are used, the mechanical stress on the metalization is kept within limits and a lower peel off strength may be acceptable to reduce the surface roughness.

#### B. Test Antenna Evaluation

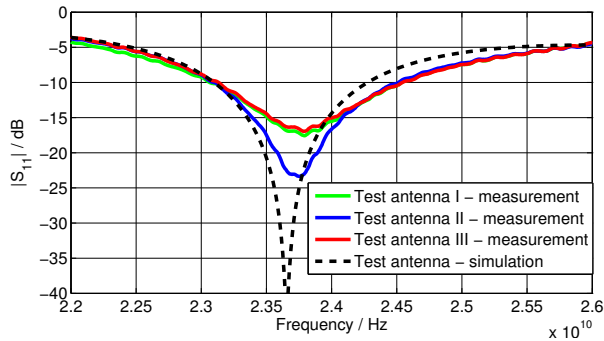
In the next step three parts of the test antenna structure described above are characterized. Therefore the G-CPW of each antenna is connected with a 24 GHz end launch connector. A simplified model of the connector is considered in the simulations of the realized prototype due to the fact that it will have a considerable impact on the antenna's properties. The vias of the G-CPW are drilled and metalized. Fig. 6 shows the simulated and measured input reflection coefficient and radiation pattern for the three realized test antennas from Fig. 5. For the input reflection measurements the connector is deembedded. As it can be seen from this the antennas provide an input matching better than 10 dB at 24 GHz. The match between the simulated and measured data is good. The resonance of the test antennas is only slightly shifted ( $\approx 100$  MHz) compared to the simulation. This indicates the reproducibility of the fabrication method. The radiation pattern is measured in an anechoic chamber. As it can be seen from this the pattern are directive as it is expected for this kind of antenna. The agreement between the simulated and measured pattern is good. The differences in the backward direction ( $\phi = 270$ ) are due to the measurement setup with the connecting cable routed in this area. The realized gain in the main direction is about 6.2 dBi for the measurements and about 5.6 dBi. It has to be mentioned that especially the front-to-back ratio of this antenna is not good. This is due to the limitation in the dimensions of the substrate material with its low height of about 2 mm.

#### C. Example Design: Dielectric Horn Antenna

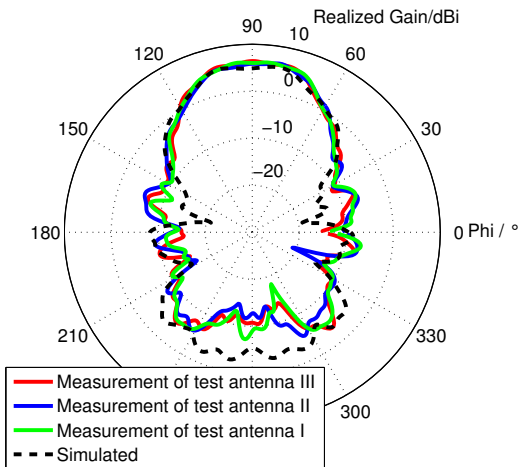
The evaluation of the last section shows the manufacturability of dielectric filled waveguide structures using LDS method at 24 GHz. In the next step the three dimensional design space should be used for an typical dielectric antenna design. The feeding structure is left similar as for the test antenna design and only the radiating part is replaced. The dielectric horn is now tapered in the horizontal and vertical plane, for example as described in [3]. To optimize the front-to-back ration the dielectric taper is partially metalized as it is shown in Fig. 7.

Fig. 8 shows the simulated results. The antenna provides an input matching of about 15 dB at 24 GHz. The radiation pattern in the horizontal plane shows a maximum realized gain of about 11.8 dBi in the main direction. The front-to-back ratio is about 22.84 dB.

Other different configurations can be developed using typical approaches for dielectric and dielectric metalized antennas as they can be found in [3], for example. Furthermore, with the 3d LDS fabrication and the possibilities of a selective



(a) Input reflection coefficient



(b) Radiation pattern in horizontal plane

Fig. 6. Measured and simulated results for prototypic dielectric horn antenna

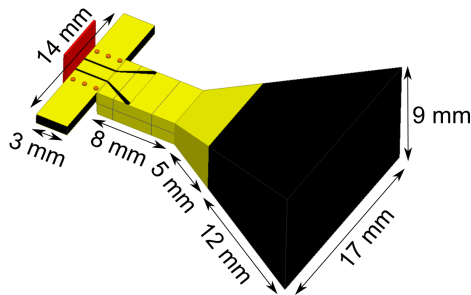


Fig. 7. CAD model of the waveguide fed dielectric horn antenna

metalization an additional design space arises. As an example, impedance surfaces can be structured on the plastic surfaces to optimize the radiation characteristic. The possibility of a direct combination of the dielectric antenna with a circuitry is an additional advantage.

#### IV. CONCLUSION

This paper presented different configurations of a dielectric horn antenna to be used at 24 GHz. The antennas are fed with a G-CPW to rectangular dielectric filled waveguide fabricated

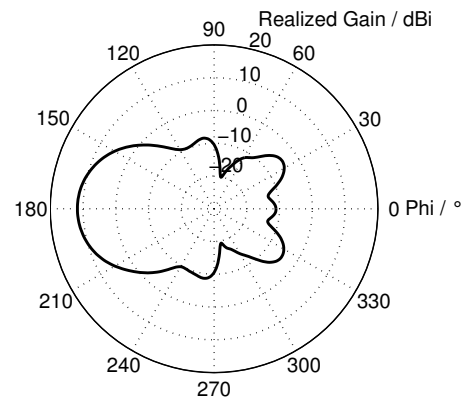


Fig. 8. Simulated realized gain pattern for dielectric horn antenna

with the LDS method. With this method the surfaces of 3d shaped injection molded parts can be arbitrarily metalized. In doing so a waveguide fed antenna together with a receiving or transmitting circuit can be efficiently realized in one piece. The possibilities that arise out of the 3d shaping and metalizing of plastic part allow additional influences on the antenna properties. In that way the design space for this type of antennas is considerably enlarged in terms of the simplicity of the manufacturing process. The three manufactured prototype antennas shown, proved the concept and the manufacturability with the LDS method at 24 GHz. The simulated and measured data are in good agreement. The example antenna structure, a dielectric horn antenna with a partially metalized taper, gives a first indication how this type of antennas, together with required circuitry, can be optimized with the 3d LDS fabrication, not only in terms of functionality but also in respect to the fabrication process itself.

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