A MID Dipole Antenna in LDS Technology

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***Abstract* — Molded interconnect devices (MID) allow the realization of electronic circuits on injection molded thermoplastics. MID antennas can be manufactured as part of device casings without the need for additional printed circuit boards or attachment of antennas printed on foil. Baluns, matching networks, amplifiers and connectors can be placed on the polymer in the vicinity of the antenna. A MID dipole antenna for 1 GHz is designed, manufactured and measured. A prototype of the antenna is built with laser direct structuring (LDS) on a Xantar LDS 3720 substrate. Measured return loss and calibrated gain patterns are compared to simulation results.**

***Keywords* — Antenna, Dipole, Laser Direct Structuring, Molded Interconnect Device, Xantar**

I. INTRODUCTION

MOLDED interconnect devices (MIDs) are polymer parts manufactured with injection molding that have electronic circuits and components placed on their surface.

In many devices polymer parts are already present. Polymers are currently used as materials for casings, spacers, but also functional parts such as handles or buttons. Typically electronic circuits are manufactured on separate parts such as printed circuit boards (PCBs), which are then fastened to the casing. PCBs offer several advantages such as multilayer designs, but many circuits can be realized without such requirements. Those electronic circuits can be manufactured directly on the polymer as a MID. Placing conductive paths and components directly on the polymers is beneficial in many applications as it allows designers to omit connectors, cables and spacers or the PCB altogether. Additionally, MID allows the production of bent and conformal circuits by adopting the shape of the plastic to the needs of the electronic circuits, again without additional materials such as circuits printed on foil. Several different processes to manufacture MIDs are currently in use. Prominent techniques are two-shot molding [1], where a platable and a non-platable resin are used during injection molding, hot embossing [2] and laser-techniques. The prototype in this paper is manufactured with a laser technique named laser direct structuring (LDS). LDS is an additive production process for molded interconnect devices from LPKF [3]. The process uses polymers that contain a special organo-metallic complex. After injection molding of the parts, the additive is activated in designed areas by laser ablation. The activated areas are then plated in currentless metal baths.

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MID can be used for electronic devices that contain antennas. MID antennas can be placed on the inside of device casings as electromagnetic waves penetrate LDS polymers. This removes the requirement for additional substrate materials for the antenna or fixating metal parts of the antenna. Cables or connectors can be omitted, as radio frequency components can be placed on the polymer together with the antenna. While MID processes only allow the production of planar antennas, conformal antennas can be built with MID and injection molding enables more complicated 3D antennas than PCB or foil printed structures.

Price reduction of 3D printers in recent years led to increased research on three-dimensional antennas. Although metal printers are available, metallization of printed polymers is often preferred. Within the shape limitations of injection molding, MID might make the mass production of those antenna designs feasible. MID antennas have recently been investigated in various applications. A bent patch antenna manufactured with LDS is discussed in [4]. In [5] measurements of a dual-polarized log-periodic antenna on a polybutylene terephthalate (PBT) substrate are presented. In vehicular applications the protective cover of automotive antenna modules can be used as substrate for MID antennas. Such an antenna module with two MIMO LTE antennas is presented in [6]. Antennas in mobile phones are already commercially built as MID [7]. LDS can be used to manufacture conformal antennas on plastic parts already present in these devices. Examples are GSM and LTE antennas in [8], [9] and [10]. LDS also allows the metallization of large parts. A LDS metalized 150 mm × 150 mm sheet was used as a ground plane for a monopole antenna in [11] to decrease the influence of a carbon-fiber reinforced polymer (CFRP) ground plane. A three-dimensional patch antenna for the global positioning system (GPS) utilizes the potential of MID technology [12]. While the bent patches are on the top layer of the substrate, the metalized bottom layer serves as a ground plane and contains a bar on which the low noise amplifier (LNA) components are placed.

A MID dipole antenna is designed, simulated, manufactured with the LDS process and calibrated gain measurements inside an anechoic chamber are discussed. Half wavelength dipole antennas are well known antennas suitable to investigate materials and production processes.

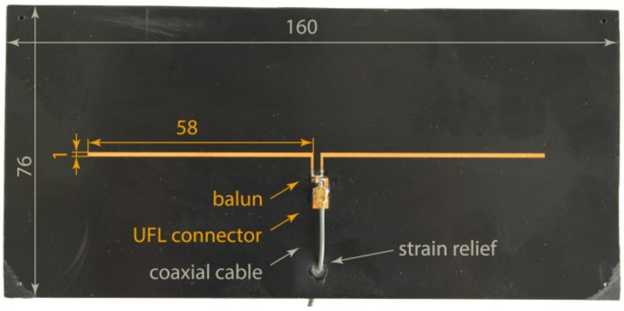

Fig. 1. Manufactured prototype of the LDS dipole antenna with balun and connector soldered onto the substrate. All dimensions in millimeter.

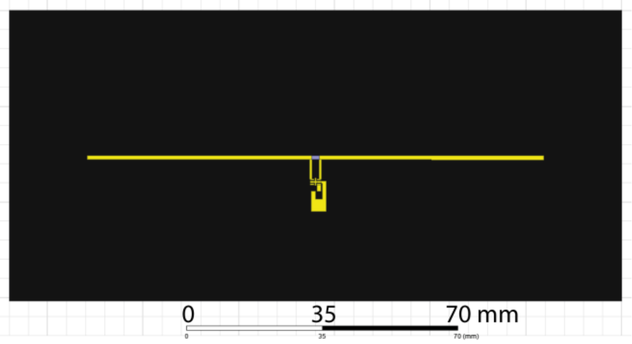

Fig. 2. Geometric model of the antenna for simulation. Metalized areas are simulated as 13 µm thick copper sheets. Balun, connector and cable are not modeled.

II. LDS Dipole Antenna Prototype and Simulation Model

The presented design is a half wavelength dipole antenna for 1 GHz. The antenna is realized as MID and manufactured with the LDS process. A balun (50/50 Ω) is placed near the dipole antenna and for measurement purposes a UFL connector is located after the balun. The manufactured prototype of the MID antenna and its dimensions are depicted in Fig. 1.

A 160mm×76mm×3mm Xantar LDS 3720 (a PC/ABS) plate is used as substrate. The metal layer consists of 6 – 8 µm copper, 5 – 7 µm nickel and 0.1 µm gold according to the manufacturer. To suspend the substrate during metallization, four small holes are drilled near the corners. Corner marks in the lower corners from production were scraped off prior to measurement. The adhesion between substrate and metal layer is temperature sensitive and requires low temperature soldering. Substrate materials for LDS with higher temperature stability have recently become available. The metal-substrate bond is also somewhat sensitive to strain. For strain relief the cable is pulled through a hole in the substrate and fixed with superglue as depicted in Fig. 1.

The antenna was simulated in Ansys HFSS, an electromagnetic field simulation program, using the finite element method. The geometry of the simulation model is depicted in Fig. 2. The simulation model includes the regions metalized with LDS but not the balun, connector, cable and strain relief. The lumped port is placed between the dipole arms. Metal layers are simulated as 13 µm thick copper sheets. The substrate material is modeled with a relative permittivity of $\varepsilon_r = 2.77$ and a dielectric loss tangent $\tan\delta = 0.00499$ according to [13]. Values for ε_r and $\tan\delta$ in [13] are obtained from resonator measurements, material properties are given for 2.69 GHz. Surface roughness is not modeled.

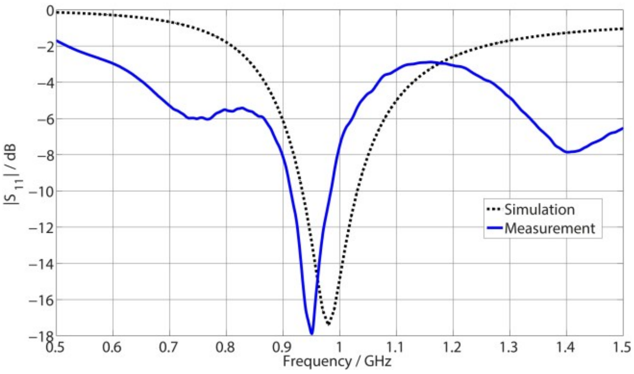

Fig. 3. Magnitude of the S-parameter of the simulated and manufactured antennas. $|S_{11}|$ is equal to the negative return loss.

III. Measurement Results

The measured and simulated values of the S-parameters are depicted in Fig. 3. The resonance frequency of the manufactured prototype is shifted to 0.95 GHz from 0.98 GHz in the simulation. This shift in resonance frequency by 3 % is acceptable for prototype production but should be considered in future designs. A return loss of 18 dB is achieved. Calibrated gain measurements are performed in the institutes' anechoic chamber. The antenna under test (AUT) is placed on a column made from Rohacell 31 IG, as depicted in Figure 4. Rohacell is a polymethacrylimide foam typically used as core material in sandwich-structured composites. In antenna applications the material is used for its air-like high frequency properties ($\varepsilon' = 1.05$ and $\tan\delta = 0.0003$ at 2.5 GHz according to manufacturer [14]).

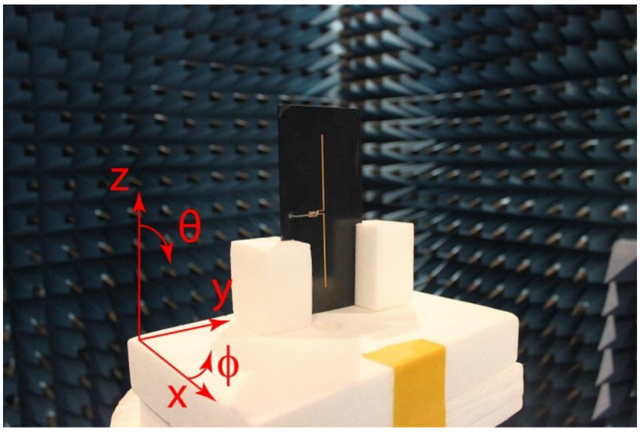

Fig. 4. Antenna under test (AUT) in the anechoic chamber. The AUT is placed on a turnable column made from Rohacell.

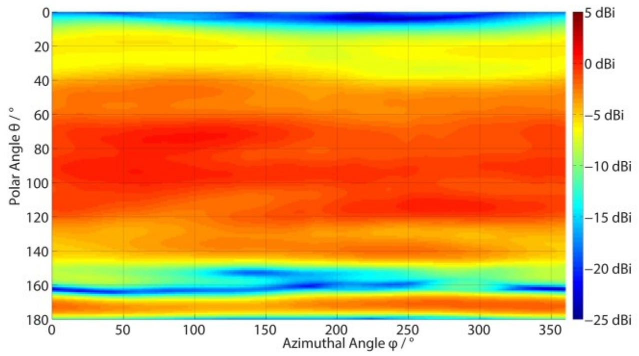

Fig. 5. Rectangular projection of the LDS dipole antenna's measured gain pattern at 950 MHz. Polar angles θ > 150° can not be measured as the θ-arm with the probe antenna is blocked by the column. Therefore, the pattern exhibits artifacts from the near-to-far-field transformation for θ > 150°.

Gain calibration is done with a NSI-RF-SG975 standard gain horn, which results in an accuracy of the absolute gain values of ±0.5 dB. Far-field results are obtained from near-field measurements with a near-to-far-field transformation. Fields under the antenna (polar angle θ > 160°) can not be measured as the column, which the AUT is placed on, blocks the θ-arm with the probe antenna. This results in artifacts in the far-field-transformed gain patterns as can be seen in Fig. 5 for θ > 150°. To minimize this effect the AUT was positioned such that one dipole-arm points downwards, as the pattern of dipole antennas has a null in that direction. Because the antenna is symmetric, these deviations do not affect the measurements too much.

Apart from the artifacts, the measured gain pattern in Fig. 5 is a typical half wavelength dipole antenna pattern. The manufactured dipole antenna shows good omnidirectional radiation, which is expected from a dipole antenna. Gain pattern cuts comparing simulation and measurement are depicted in Figures 6 and 7. Fig. 6 compares a horizontal pattern cut for polar angle θ = 90° to the simulation result. The measured maximum gain of the prototype (0.45 dBi) is a bit less than the maximum gain in the simulation (0.92 dBi). The horizontal cut of the gain pattern in Fig. 6 is omnidirectional with variations < 1 dB. The balun, connector and cable are small compared to wavelength and don't appear to have a noticeable influence on the radiation pattern of the antenna. Fig. 7 depicts a vertical cut of the gain patterns for φ = 0°. As in Fig. 5 measurement artifacts can be identified for polar angles θ > 150°. The gain pattern has small ripples of about 2 dB. Measured efficiency at 950 MHz is 65 %. Overall the simulation results are in good agreement with measurements.

IV. Conclusion

A MID dipole antenna in LDS technology was designed, manufactured and measured.

In the simulation model the electromagnetic material properties of the Xantar LDS 3720 substrate material are taken from [13], simulation results are in good agreement with measurements of the manufactured prototype.

From a practical point of view the metalized layers peel off the substrate easily, this imposes strong mechanical requirements for the antenna feed point.

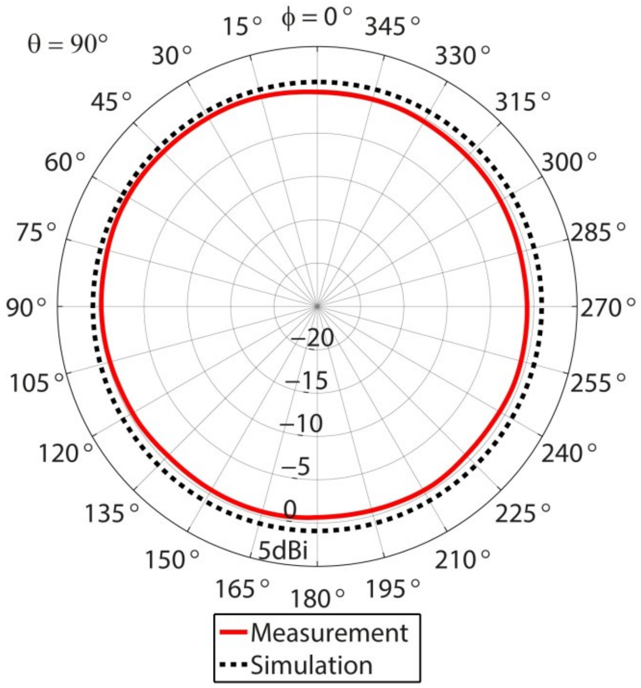

Fig. 6. Horizontal cut of the gain patterns for polar angle θ = 90° at 950MHz.

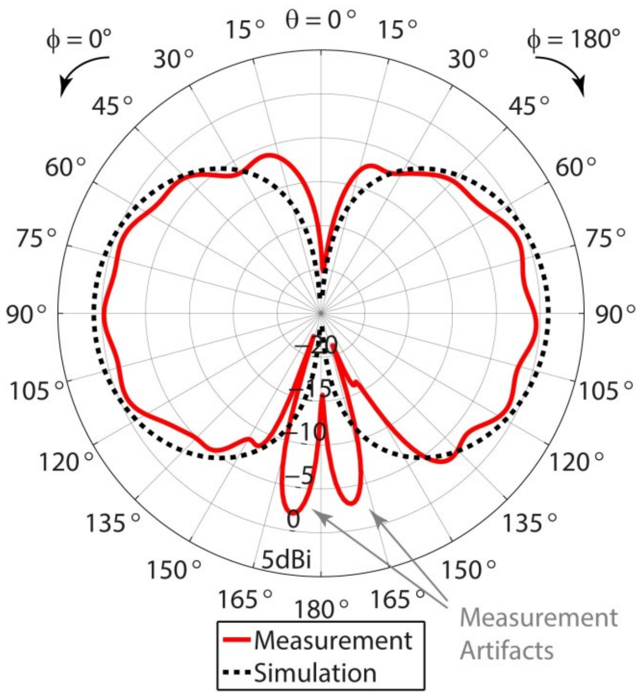

Fig. 7. Vertical cut of the gain patterns for azimuthal angle φ = 0° at 950MHz. Lobes close to 170° are artifacts from the near-to-far-field transformation as polar angles θ > 160° can not be measured in the anechoic chamber.

ACKNOWLEDGMENT

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REFERENCES

[1] A. Islam, H. N. Hansen, P. T. Tang, M. B. Jørgensen and S. F. Ørts, "Two-component microinjection moulding for MID fabrication," in *Plastics, Rubber and Composites*, vol. 39, no. 7, 2013.

[2] A. Kilian, J. Weinzierl and L. P. Schmidt, "Investigation of the Hot Embossing Technology for Low-Cost Antennas Printed on Polymer Substrates", in *European Microwave Conference (EuMC)*, Amsterdam, Netherlands, 2008.

[3] N. Heininger, W. John and H. J. Boßler, "Manufacturing of Molded Interconnect Devices from Prototyping to Mass Production with Laser Direct Structuring," in *International Congress Molded Interconnect Devices*, Fuerth, Germany, 2004.

[4] D. Kornek, E. Slottke, C. Orlob and I. Rolfes, "Experimental Investigation of Bent Patch Antennas on MID Substrate," in *European Conference on Antennas and Propagation (EuCAP)*, Barcelona, Spain, 2010.

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

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

[7] C. Rowell and E. Y. Lam, "Mobile-Phone Antenna Design," in *IEEE Antennas and Propagation Magazine*, vol. 54, no. 4, pp. 14-34, 2012.

[8] 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," in *Loughborough Antennas and Propagation Conference (LAPC)*, Loughborough, United Kingdom, 2012.

[9] F. Sonnerat, R. Pilard, F. Gianesello, F. Le Pennec, C. Person and D. Gloria, "Innovative LDS antenna for 4G applications," in *European Conference on Antennas and Propagation (EuCAP)*, Gothenburg, Sweden, 2013.

[10] A. Cihangir, F. Ferrero, C. Luxey, G. Jacquemod and P. Brachat, "A Bandwidth-Enhanced Antenna in LDS Technology for LTE700 and GSM850/900 Standards," in *European Conference on Antennas and Propagation (EuCAP)*, Gothenburg, Sweden, 2013.

[11] G. Artner, R. Langwieser and C.F. Mecklenbräuker, "Material Induced Changes of Antenna Performance in Vehicular Applications," in *IEEE International Conference on Microwaves, Communications, Antennas and Electronic Systems (COMCAS)*, Tel Aviv, Israel, 2015.

[12] A. Friedrich, L. Berkelmann, T. Martinelli, B. Geck, O. Klemp and I. Kriebitzsch, "An active three-dimensional GPS patch antenna using MID-technology," in *European Radar Conference (EuRAD)*, Paris, France, 2015.

[13] Q.H. Dao, A. Friedrich and B. Geck, "Characterization of Electromagnetic Properties of MID Materials for High Frequency Applications up to 67 GHz," in *International Congress Molded Interconnect Devices*, Nuremberg / Fuerth, Germany, 2014.

[14] Evonik Industries, "Rohacell Dielectric Properties," Darmstadt, Deutschland, 2011.