3D Printed Antennas for Mm-wave Sensing Applications

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***Abstract*—This paper presents three low cost 3D printed antenna concepts for integration with a miniature mm-wave platform. The proposed solutions are optimized to operate in mm-wave ISM band (122GHz-123GHz). Different, inexpensive, detachable antennas can be used with the same platform for various RF sensing applications such as food safety, health and industrial.**

Keywords—3D printing, lens antenna, RF sensing)

I. INTRODUCTION

Millimeter wave (mm-wave) and terahertz (THz) technology have been around for decades. For years, little happened in this domain, which was difficult to reach with conventional Integrated Circuit (IC) technology at the lower frequency end and requires relatively large and expensive sources and detectors at the higher frequency end. Today though, mm-wave and THz are at the forefront of sensing and imaging [1]-[3]. Advances in circuit and processing technology are among the key reasons. This opens the door for creating advanced miniature Radio Frequency (RF) sensing platforms, which can be physically integrated into the portable devices (e.g. mobile phones).

The antenna is one of the essential building blocks in any RF wireless system. Usually, the antenna parameters are fixed based on the target specification. This may be especially the case for miniature devices with a small footprint and limited power. Such RF wireless systems cannot readily provide flexibility in the terms of radiation performance (i.e., gain and beamwidth).

Our objective is to provide this flexibility at low cost using 3D printed antennas. Such antenna demonstrate promising performance and potential for integration with mm-wave systems [4]-[7]. The idea is to design a platform in which the required antenna can be mechanically replaced. This is accompanied by a technique that takes into account the possibilities and limitations of 3D printing and allows us to design and print a new antenna according to the required performance and then connect it to the platform. Replaceable printed antennas, optimized for radiation performance, can be used like changing "head" of the RF sensor or probe. By using a 3D printer, we can rapidly prototype various different plastic antennas. The prototyped antennas can be attached to the miniature platform board and provide the required radiation performance.

The research leading to these results has received funding from the EU Framework program Horizon H2020 under grant agreement no. 644039 and was carried out in the frame of M3TERA project (Micromachined terahertz systems - a new heterogeneous integration platform enabling the commercialization of the THz frequency spectrum).

Three dielectric focusing antenna solutions are proposed as an example: 1) a rod antenna, 2) flat sectoral lens antenna and 3) a 3D lens antennas. Due to the high operational frequency band (center frequency = 122.5GHz) the antenna modules will be of relatively small size.

One of the most commonly used antennas at mm-wave frequencies is an open end waveguide (WG) [10]. The mm-wave miniature platform will use the hollow WG as a transition between the MMIC and free space and additional antenna solutions, such as dielectric resonator antenna (DRA), dielectric lens antenna (DLA). The rectangular waveguide is usually operated at TE10 mode, which provides linear polarization. An example of the wave guide model is provided by the structure illustrated in Fig.1 (H2020 M3TERA project). The overall length of the structure is 10mm. A 1.65×0.8mm rectangular hole (waveguide) is micromachined inside the silicone bloc.

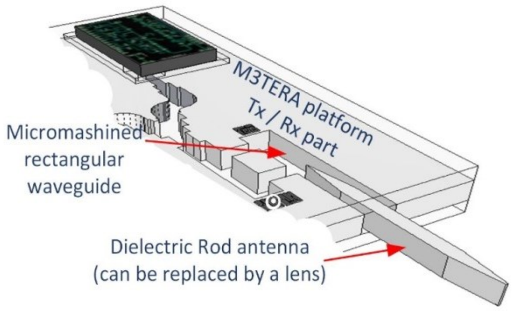


Fig. 1. M3TERA miniature mm-wave platform concept.

Section II explains the design of the lens antenna and the dielectric rod antenna. Then, in Section III, and Section IV antenna prototyping and measurements are discussed. Conclusions are presented in Section V.

II. ANTENNAS DESIGN

Our dielectric lens antenna is the combination of an electromagnetic lenses and a feed. This antenna belongs to the optical antenna type and is attractive in the mm wave band in order to create a relatively narrow radiation pattern. In our case, the lens antenna is used as an additional element with the open WG antenna, improving and modifying its radiation characteristics. The lens antenna is tightly attached and mechanically fixed to the open WG aperture. During the test, the lens is attached to the WR-10 (UG-387) flange as shown in Fig.11.

A. Lens antennas (LA)

This sub-section presents two relatively simple collimator lens antenna designs. The first one has a planar structure and is designed to focus the beam in one plane. This lens antenna will yield a fan beam radiation pattern. The second lens antenna offers hemispheric coverage and optimized to focus the beam in both E and H planes. The lens antennas were designed and optimized with ANSYS HFSS EM software.

Both lens antennas were initially designed taking into account the lens material (Table 1) properties and the excitation source. Fine tuning was done using the HFSS parametric optimizer.

TABLE I. RESIN MATERIAL EM PROPERTIES

Acrylate polymer	
Relative permittivity (ε)	~3
Dielectric loss tangent (tgδ)	6×10^{-4}

Fig.2 shows the first planar lens antenna design. The antenna is tightly attached to the waveguide output by its planar surfaces as depicted in Fig.11. The longest lens side is perpendicular to the WG H-plane. Such length location favors directive radiation pattern in H-plane. The flat lens is very compact and can be easily integrated into portable devices. The antenna dimensions are provided in Fig.2.

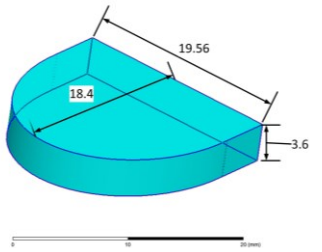
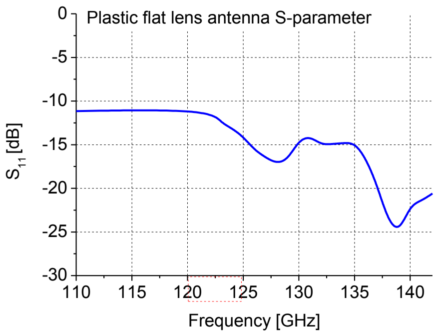
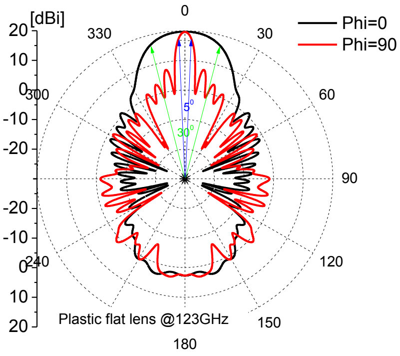


Fig. 2. 3D plastic flat lens antenna: theoretical HFSS model (dimensions are mm).



(a)



(b)

Fig. 3. 3D flat lens antenna theoretical performance: S-parameter (a) and Radiation pattern (b) at 122GHz

The antenna theoretical performance is presented in Fig.3. It is well matched in the ISM (122-123GHz) band. The maximum gain is around 19dBi with only 5 degree HPBW in H-plane. As expected, the antenna HPBW in E-plane is larger and reaches 30 degrees. Designed flat lens side lobes level is around -12dB.

The second 3D lens antenna is half ellipsoid (Fig.4). In comparison with the planar lens solution, the 3D lens volume in E-plane is larger. The optimized lens dimension is shown in Fig.5. Due to the larger lens volume in E-plane, the antenna gain is increased to 22dBi with lower HPBW in E-plane to 22 degree. The SLL is similar to the flat solution around at -12dB.

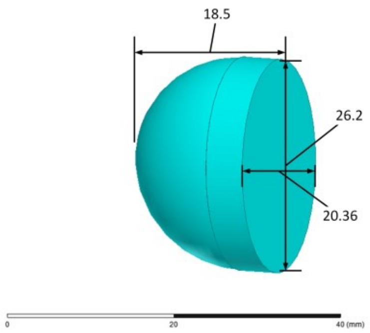
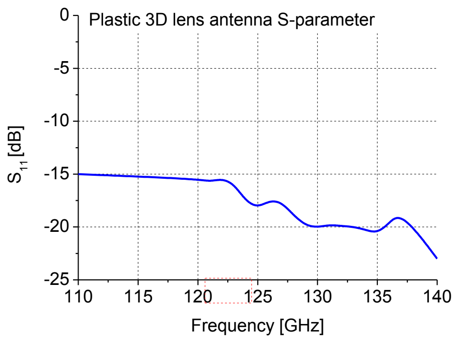
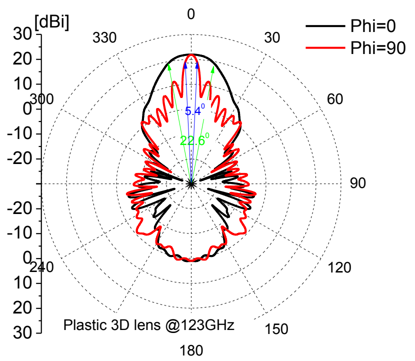


Fig. 4. 3D plastic lens antenna: theoretical HFSS model (dimensions are mm).

The antenna is well matched at ISM band (122GHz-123GHz) as shown in Fig.5.



(a)



(b)

Fig. 5. 3D lens antenna theoretical performance: S-parameter (a) and Radiation pattern (b) at 122GHz

B. *Dielectric Rod Antenna (DRA)*

The DRA antenna is relatively simple to design and optimize. At mm- wave frequencies, dielectric rod antennas provide significant performance advantages for lower cost compared to high gain antennas such as horn antennas, which are often more expensive, bulky and difficult to manufacture. 3D printer use makes this antenna even more attractive.

The DRA modelling and optimization was performed with Ansoft HFSS. Optimization of the DRA matching part and length is done by HFSS parametric optimization.

The optimized dielectric rod antenna (DRA) has a rectangular cross section with a sectional taper in the E-plane (Fig.6). The rod matching section, which is located inside the rectangular WG, acts as smooth transition between the waveguide and WG aperture. The DRA resin material property is provided in Table 1.

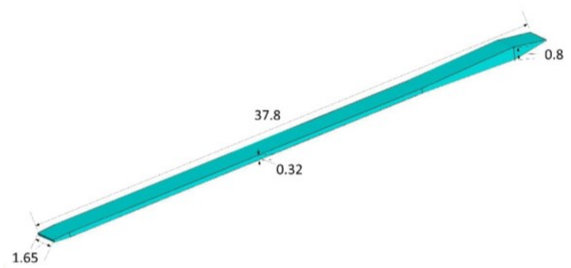
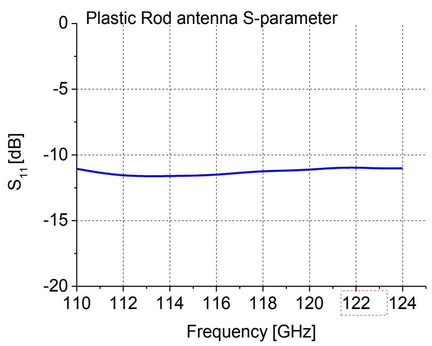
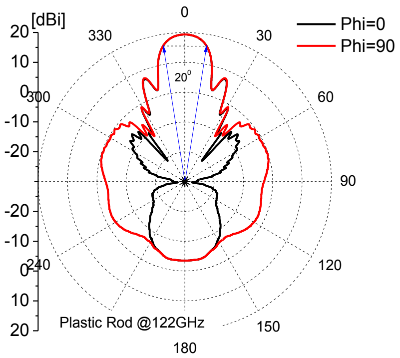


Fig. 6. Rod antenna: theoretical model (dimensions are mm).



(a)



(b)

Fig. 7. Rod antenna theoretical results: S-parameters (a) and radiation pattern (b) at 122GHz.

Fig.7 shows that the optimized DRA yields a high gain (20dBi) with identical radiation patterns in the E and H planes (HPBW=20degree).

III. ANTENNA PROTOTYPING

A REIFY 3D printer [9] has been used for prototyping. This is a stereo-lithography printer based on a DLP projector as presented in Fig.8. The antenna material is acrylate polymer, which parameters are presented in Table 1.

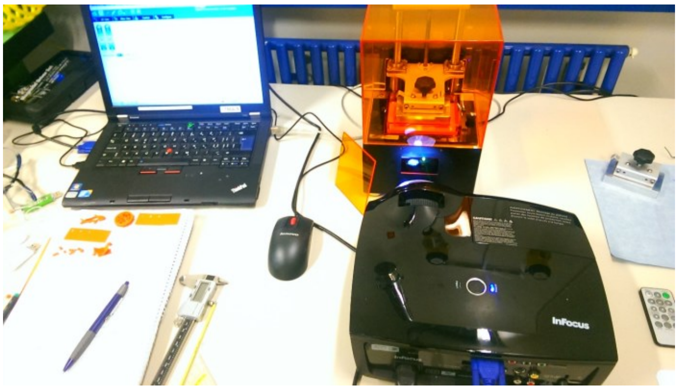


Fig. 8. 3D printer “REIFY 3D” for the antenna prototyping

A resin material property used during the prototyping is provided in Table 1.

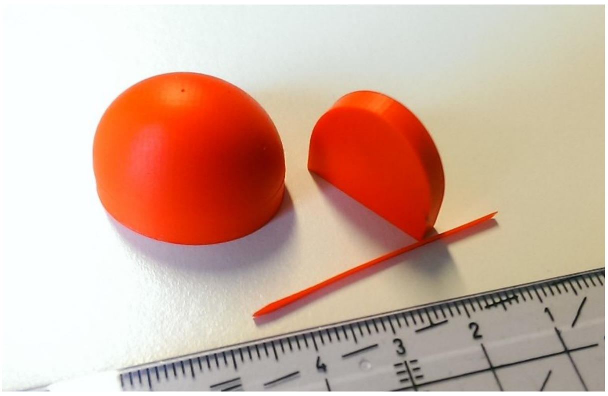


Fig. 9. Prototyped plastic antennas.

The antennas have been prototyped with better than 0.08mm accuracy (Fig.9).

IV. ANTENNA CHARACTERISATION

In a next step, the antenna radiation characteristics will be measured in the CSEM anechoic chamber. The antenna measurement setup is presented in Fig.10 and Fig.11. The antenna will be measured in the vertical and horizontal positions. At the time of the writing of this paper, the measurement results are not available and will be presented later during the oral presentation of the paper.

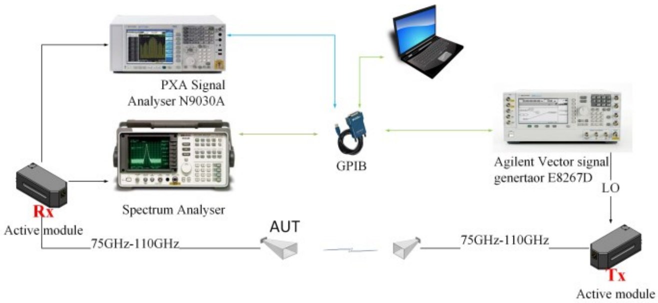


Fig. 10. Antenna measurement setup

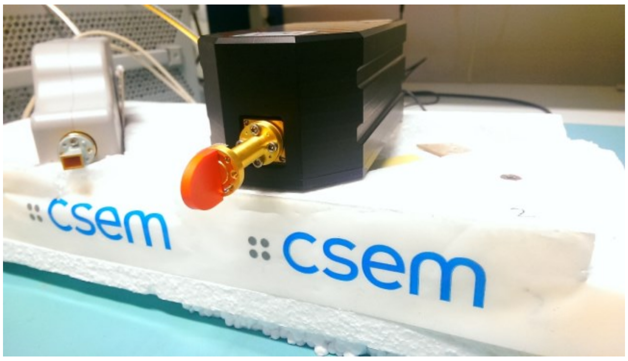


Fig. 11. 3D flat lens antenna attached the open end WG.

V. CONCLUSION

Inexpensive 3D printing technology can be used to create a large pallet of antennas suited to cover the needs of various different RF sensing applications. Using a 3D printer, we can rapidly prototype different plastic antennas that can be mechanically fitted to sensing platform and thus optimize the radiation.

Three different low cost plastic 3D printed antenna solutions: flat lens, a 3D lens and a rod, have been designed, optimized and prototyped. The antennas are optimized to operate at mm-wave ISM band (122GHz-123GHz) and demonstrated to work for various RF sensing applications; the techniques used can be easily extended to realize similar antennas at other mm-wave frequency bands.

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