3D-PRINTED LENS FOR HIGH DIRECTIONAL LOW-PROFILE ANTENNA

Jaroslav Zechmeister

Doctoral Degree Programme (1), FEEC BUT

E-mail: xzechm02@stud.feec.vutbr.cz

Supervised by: Jaroslav Lacik

E-mail: lacik@feec.vutbr.cz

Abstract: This contribution focuses on 3D-printed lenses for a high directional low-profile antenna for 77 GHz. Two 3D-printing technologies and two different materials are used for the lens fabrication. A dielectric constant and a conductivity of these materials were measured with a transmission/ reflection measurement method. The realized antennas with the designed lenses have gain more than 27 dBi and angular width of the main lobe below 6°.

Keywords: 3D-printed lens, dielectric lens, lens antenna, transmission/ reflection measurement method

1 INTRODUCTION

3D-printing is a fast-growing technology which is usable in many branches [1], even microwave technologies. Main advantages of the 3D-printing are different printing possibilities, a speed of manufacturing and a product price versa to traditional manufacturing technologies. Moreover, nowadays a cheap 3D-printers are available. Therefore, they are accessible for all small companies or homes.

The 3D-printers are mostly based on two printing principles. A fused deposit manufacturing (FDM) is example of the 3D-printing technology which based on an extruding a melted material through a tiny nozzle for build the final structure. The second common principle of the 3D-printing is based on a building the structure on a bed of a powder, a sheet or a fluid material. An example of this principle is a stereolithography (SLA) which is based on a hardening of a liquid photopolymer resin by an ultraviolet laser to build the final structure.

Some studies of the 3D printed dielectric lens have been already published. In [2] a 3D printed multi-layered dielectric lens for 10 GHz band is presented. In [3] a perforated dielectric lens for 60 GHz band is studied. A discrete dielectric lens antenna for terahertz applications is presented in [4].

In this contribution, the possibilities of the 3D-printed dielectric lens for use in a low-profile antenna are studied. The antenna was considered to use in an antenna system for a 77 GHz car radar, therefore the profile of the antenna should be very low. The profile of the antenna was considered to 40 mm. Furthermore, the attention was focused on an antenna gain, an angular width of the main lobe and a side lobes level.

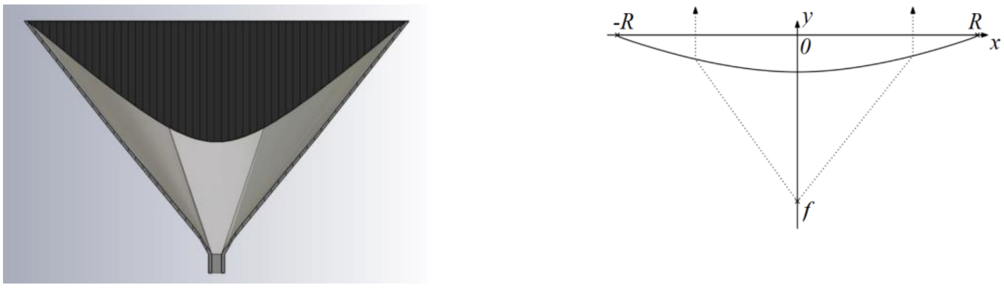
2 DIELECTRIC LENS DESIGN

2.1 HYPERBOLIC LENS DESIGN

A hyperbolic lens was chosen due to the geometrical properties. This lens has curved only one side (Figure 1), therefore the lens does not interfere above the aperture plane. It is an advantage in this case due to the limit of the antenna profile. For design of the hyperbolical lens the equation (1) published in [5] was used. The equation

$$y = \frac{-\left(\sqrt{\varepsilon_r(R^2-f^2)}-f\right)+\sqrt{\left(\sqrt{\varepsilon_r(R^2-f^2)}-f\right)^2-(\varepsilon_r-1)(R^2-x^2)}}{\varepsilon_r-1} \quad (1)$$

describes a shape of the curvature of the lens, where ε_r is a relative permittivity, R is a radius of lens, f is a focal length and x is a distance of the centre of the lens.

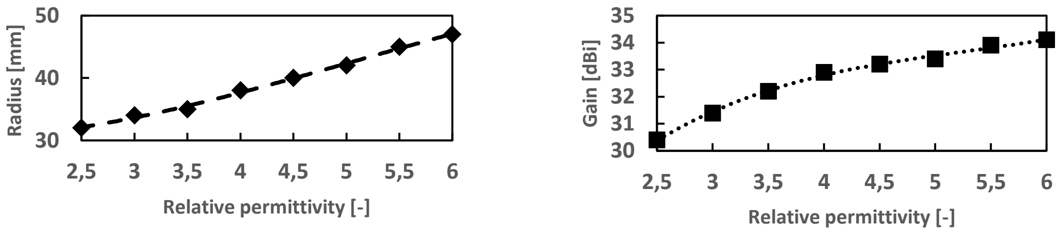


a) b)

Figure 1: Model of antenna with hyperbolic lens a) and hyperbolic lens scheme b).

2.2 MATERIAL OF DIELECTRIC LENS

The gain of the hyperbolical lens antenna fed by a horn antenna (Figure 1a) is enhanced by increasing of the aperture radius. The radius can be enlarged to the point where the radiation energy begins to flow to the side lobes. At this point, the maximum gain is obtained. In Figure 2a the dependence of the ideal radius to the relative permittivity of the lens is shown. The achieved gain for the ideal radii is also shown in Figure 2b. Obviously, it is advantageous to choose the material with the relative permittivity around 3.5 considering the achieved gain and the ideal radius of aperture.



a) b)

Figure 2: Dependence of ideal radius a) and maximal gain b) on the relative permittivity of lens material.

2.3 MATERIAL MEASUREMENT

Two chosen materials for the 3D-printing, an ABS material and a photopolymer, and two materials which are usually used for the dielectric lens fabrication, a silon and an ertacetal, were measured. For the measurement, the T/R method [3] was used. The method is based on the measurement of scattering parameters of a sample located in a sample holder. In this case, a piece of a waveguide WR10 was used as the sample holder. The measured relative permittivity and conductivity of the measured ABS material and photopolymer are shown in Figure 3. The measurement of the conductivity is very sensitive to an influence of the measurement setup. Therefore, the measurement of the conductivity shows the similar deviations for the case of the ABS material and the photopolymer, respectively. The comparison of the measured properties for the measured materials at 77 GHz are shown in Table 1.

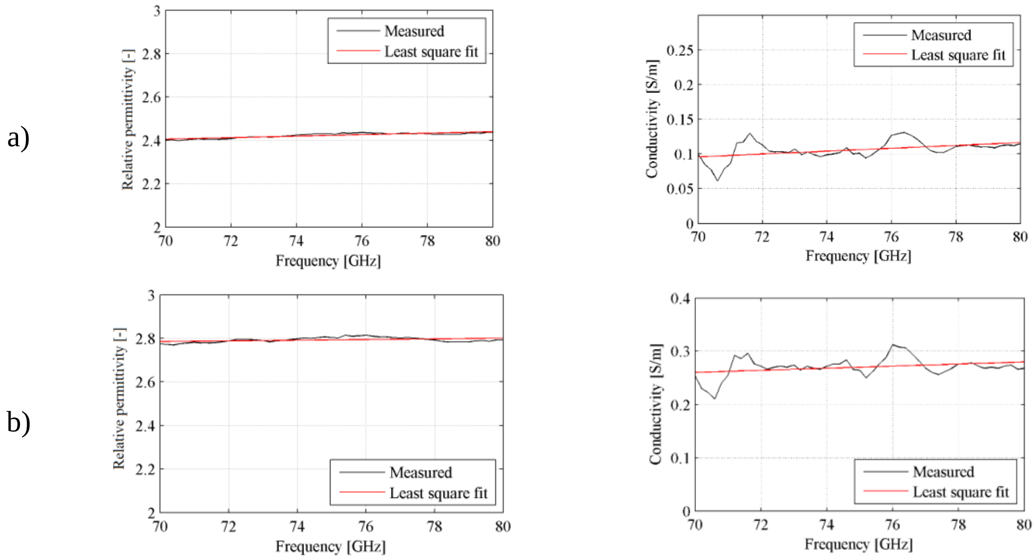


Figure 3: Measured frequency dependence of relative permittivity and conductivity of ABS material a) and photopolymer b) for frequency band 70 – 80 GHz.

Material	Dielectric constant [-]	Conductivity [S/m]
ASB	2.42	0.11
Photopolymer	2.8	0.27
Silon	2.58	0.11
Ertacetal	2.7	0.14

Table 1: Measured properties of materials for dielectric lens at 77 GHz.

2.4 NUMERICAL MODELS

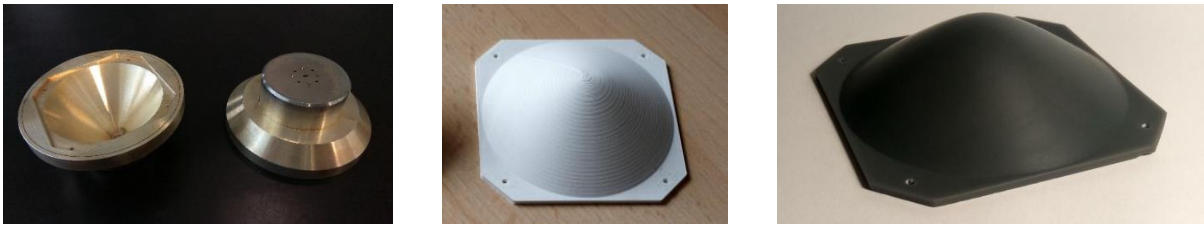
The measured parameters of the materials were used for the design of the dielectric lenses. The theoretical maximum gain of the antenna with the ABS lens is 30.2 dBi and with the photopolymer lens 31 dBi. However, these values are theoretical, considering lossless materials and the ideal radius of the aperture. For the numerical models, the measured losses of the materials were included and the radius of the aperture was chosen 33 mm which represents compromise between the ideal radii for the ABS material and the photopolymer. The optimized antenna with the lens made from the ABS material has at 77 GHz the gain 27.7 dBi and the angular width of the main lobe in the E-plane and the H-plane is 4.1˚ and 6.5˚, respectively. The level of the side lobes was more than 20 dB below the maximal value. The simulated gain of the antenna with the photopolymer lens is 27 dBi, the angular width of the main lobe in the E-plane and in the H-plane are 3.5˚ and 5.7˚, respectively. The level of the side lobes is 19 dB below the maximum value.

3 REALIZATION

3.1 LENS FABRICATION

A metallic part of the antenna was fabricated by RAMET a.s. The brass horn (Figure 4a) has the aperture radius 33 mm, like the lenses, and the profile 40 mm. A surface of the horn antenna was chemically silvered to increase surface conductivity.

The ABS lens was fabricated by the FDM 3D-print technology (Figure 4b). Printed layers on the surface of the fabricated lens are evident. On the other hand, the surface of the photopolymer lens (Figure 4c) is almost perfectly smooth. However, the photopolymer lens in contrast to the ABS lens has a poor geometrical precision primarily proving by an eccentricity.



a) b) c)

Figure 4: The brass horn a), the ABS lens b) and the photopolymer lens c).

3.2 EXPERIMENTAL RESULTS

For the verification of the numerical models, fabricated lenses were placed on the aperture of the horn and the gain of the resultant structures were measured in an anechoic chamber. For the ABS lens, the measured value of the gain in the main direction is 27.9 dBi. The measured gain radiation patterns compared with the simulated data are shown in Figure 5a and 5b. The comparison between the simulated and the measured values of a reflection coefficient is shown in Figure 6a.

The antenna with the photopolymer lens achieved the maximal value of gain 27.6 dBi. The comparison between the simulated and the measured radiation patterns is shown in Figure 5c and 5d. The frequency dependence of the reflection coefficient can be seen in Figure 6b. The measurement is compared with the simulated values in Table 2.

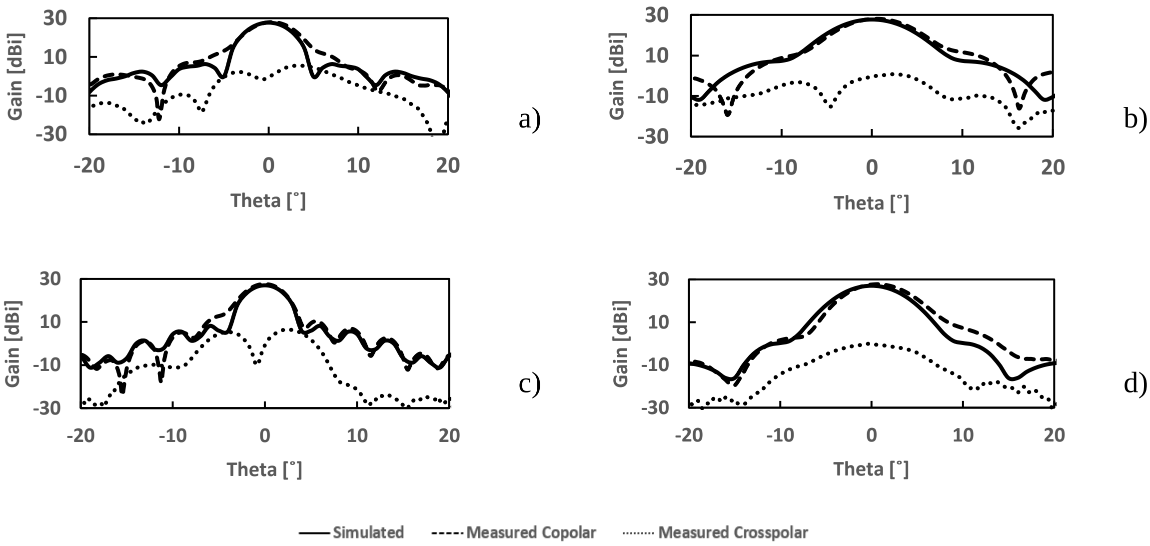


Figure 5: Comparison between measured and simulated gain of antenna with ABS lens in E-plane a) and H-plane b) and of antenna with photopolymer lens in E-plane c) and H-plane d).

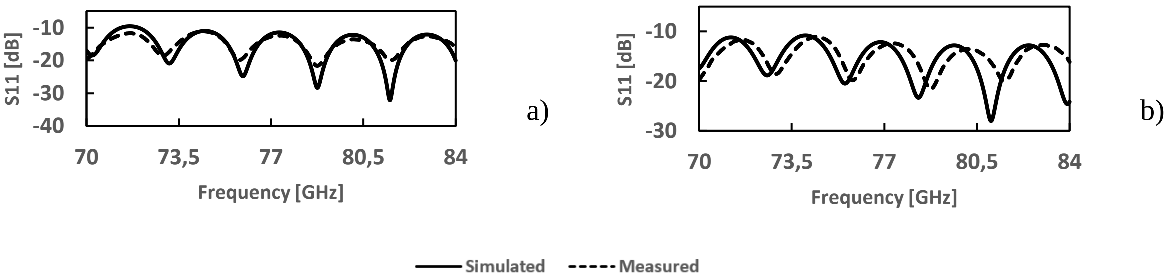


Figure 6: Comparison between measured and simulated S11 of antenna with ABS lens a) and photopolymer lens b).

Material of lens	Simulated			Measured		
	G [dBi]	θ_E [˚]	θ_H [˚]	G [dBi]	θ_E [˚]	θ_H [˚]
ABS	27.7	4.1	6.5	27.9	3.8	5.5
Photopolymer	27	3.5	5.7	27.6	3.8	4.5

Table 2: Comparison between simulated and measured values of gain and angular width in E-plane and H-plane

4 CONCLUSION

The 3D-printed lens for the high directional low-profile antenna for 77 GHz frequency band have been presented. The designed lenses were fabricated by the FDM and the SLA 3D-printing technologies. The measured results are equal to the simulations. The antenna with the ABS lens achieved the gain of 27.9 dBi and with the photopolymer lens the gain of 27.6 dBi. The achieved aperture efficiency of the antenna with the ABS lens and the photopolymer lens was 21 % and 18 %, respectively. The achieved results show that 3D-printed dielectric lenses are usable up to W frequency band.

ACKNOWLEDGEMENT

Thank belong to Zbynek Lukes for many helpful comments and Ramet a.s. for the horn antenna fabrication and support. The research was supported by the Internal Grant Agency of Brno University of Technology project no. FEKT-S-17-4713. For simulations and experiments the infrastructure of the SIX Centre was used.

REFERENCES

[1] J. Hornick and D. Roland, "3D Printing and Intellectual Property: Initial Thoughts", *The Licensing Journal*, vol. 33, no. 7, pp. 12-16, 2013.

[2] P. Mahouti, M. Belen, F. Güneş and R. Yurt, "Design and realization of multilayered cylindrical dielectric lens antenna using 3D printing technology", *Microwave and Optical Technology Letters*, vol. 2018, no. 14, p. xocs:firstpage xmlns:xocs=""/, 2019.

[3] J. Pourahmadazar, S. Sahebghalam, S. Abazari Aghdam and M. Nouri, "A Millimeter-Wave Fresnel Zone Plate Lens Design Using Perforated 3D Printing Material", in *2018 IEEE MTT-S International Microwave Workshop Series on Advanced Materials and Processes for RF and THz Applications (IMWS-AMP)*, 2018, pp. 1-3.

[4] S. Qu, H. Yi, C. Chan and K. Ng, "Low-cost discrete dielectric terahertz lens antenna using 3D printing", in *2014 IEEE Conference on Antenna Measurements & Applications (CAMA)*, 2014, pp. 1-3.

[5] Kuriyama, H. Nagaishi, H. Kuroda and K. Takano, "A high efficiency antenna with horn and lens for 77 GHz automotive long range radar", in *2016 13th European Radar Conference, EuRAD 2016*, 2017, pp. 378-381.