On the Surface Roughness and Smoothing in the 3D Printed THz Reflectors

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***Abstract*—This paper presents the effect of surface roughness on the performance of the 3D printed near field focused THz Cassegrain antenna configuration. It is found that the roughness affects the focal plane parameters. The nearfield directivity is reduced by ~ 3.5 dB for 60 µm rough surface, there is only a small effect on the focus spot width. A smoothing process, which reduces the conductive coating surface roughness to 4 µm, is also described. The roughness loss is less than 0.1 dB at 300GHz.**

***Keywords*— 3D printing; reflectors; surface roughness; THz**

I. Introduction

3D printing has been widely used recently in fabricating various antenna structures [1]-[3], since it allows inexpensive and fast prototyping of the materials with high precision. In general, 3D printers slice the model into thin stacked layers which creates the possibility of random surface errors as there is a tolerance allowed in the precision of the manufacturing. In practice, the measure of the fabricated structure accuracy is the surface root mean square (rms). For the THz frequency range, where the wavelength is small (in mm), surface inaccuracy of tens of micron can lead to serious performance degradation. For instance, in case of high directivity THz reflectors, random surface errors can lead to loss of peak directivity. In [4], we presented a 3D printed near field focused THz cassegrain reflector antenna for detecting EM side-channel signals at a distance. It was observed that the surface roughness and smoothing process plays significant role in the reflector performance at THz frequencies. While the effect of the surface roughness on the far field metallic reflectors performance has been well known in the microwave range [5]-[6], these effects have not been discussed much at the THz frequencies for 3D printed near field reflectors. Here, we present the effect of surface roughness on the focus properties and parameters of the near field focus 3D printed THz reflector. Also, to reduce the roughness loss, the smoothing process in the fabrication has been discussed.

II. Antenna Modeling & Smoothing

The reflector's design and modeling is done in CST v 2017 [7]. To model surface, we used random Gaussian surface roughness, similar to [8]. Gaussian surface roughness is described by two parameters, standard deviation and correlation distance. In this study, we fix the correlation distance to 1mm and vary the standard deviation from 0 to 120 µm. Fig. 1 shows the 3D reflector antenna which includes rough surface modeling.

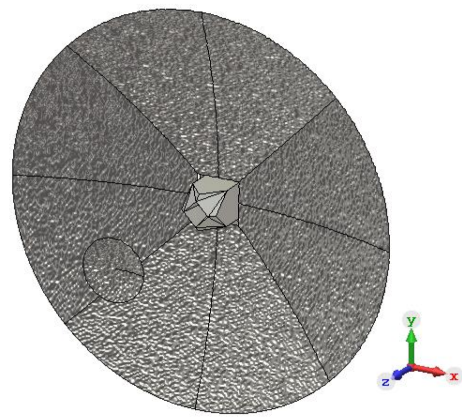

Fig. 1 Picture of 3D model in CST showing the rough reflector surfaces.

3D printing technique is used to fabricate both the secondary and the primary reflectors. The printer slice the model into thin stacked layers along the z-axis. Therefore, an important measure of quality for 3D printing is the layer thickness. Since curved features along the z-axis will show a staircase approximation in the finished prototype, working with smaller layer thickness will result in more accuracy. The printer used is FORMIGA P 110 [9], has a layer thickness of 60 µm. This thickness can give acceptable accuracy in the lower end of mm-wave range. However, for the THz frequency range (300 GHz), small imperfections on the reflector surfaces lead to phase error losses and can significantly affects the performance parameters like focused directivity, the spot size, and shape. For this reason, additional smoothing had to be applied to the surface of reflectors. The smoothing and conductive coating process is described below:

- First, a thin single coat of a wet sandable automobile primer was applied to the fabricated prototype surface. This primer provides a surface that is easier to smooth, and for the conductive paint to adhere to.

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- Next, the surface was smoothed using first 600 then 1200 grit sanders. This process is implemented carefully so as not to effect the shape and geometry of the reflectors and only remove the nonidealities of the surface created by printer.

- The smoothed surface is now ready for the conductive paint to be applied. Here, we use the MG Chemicals silver paint. There are many different brands of conductive paint with several methods of application. The most convenient products would be aerosol cans; however, for this prototype, 0.2 mm nozzle airbrush was used to spray pure silver paint on the prototype at 20 cm distance to get uniform coating. This method allows for greater control over how the paint is dispersed and ensures the best quality of surface conductivity.

- Finally, to polish the conductive coated surface, 3000 grit sanders are used on the reflector surface. A 3000 grit sander has an average particle diameter of around 3 μm.

The outlined method resulted in a conductive surface that very well matched the simulations using perfectly smooth PEC surfaces.

III. Surface Roughness Effects

This section presents the results and discusses the effects of surface roughness. In theory, the standard deviation of the surface roughness, σ_s, effects the peak directivity by the factor of [10]

$$\exp\left[-\left(\frac{4\pi\sigma_S}{\lambda}\right)^2\right] \quad (1)$$

Fig. 2 shows the theoretical roughness loss compared with the simulated loss. The 3D printed and conductive coated prototype was measured to have 0.7 dB total loss. The surface roughness of the paint, the conductivity of the paint, and the obstruction of the struts contribute to the total loss. The method described in Section II resulted in a surface roughness of 4 μm. The measurement was done using a GR280 surface roughness tester. The roughness loss for 4 μm is less than 0.1 dB.

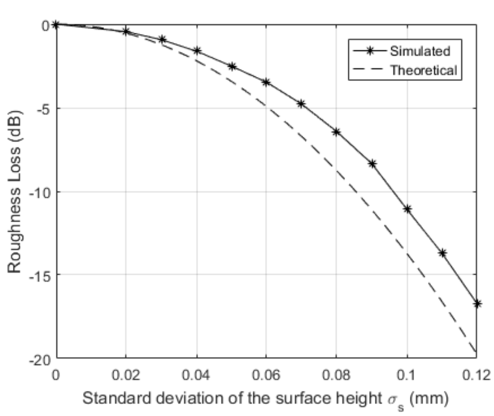
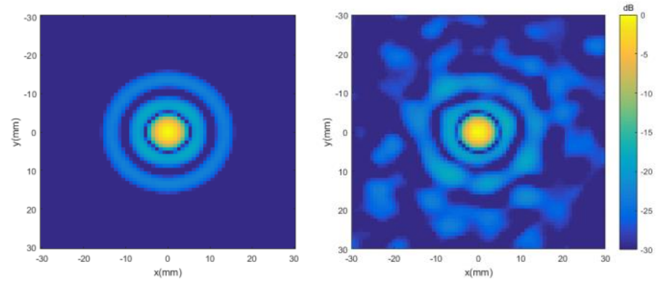


Fig. 2 Peak near field focused directivity loss w.r.t surface roughness.



(a) (b)

Fig. 3 Focal plane relative power density for smooth and rough ($\sigma_s = 60\ \mu m$) reflectors.

Fig. 3 shows the relative power densities on the focal plane for reflectors with different surface roughness values (perfectly smooth and 60 μm). There is no significant effect on the width of the focus; however, due to the scattered fields the nearfield directivity is reduced by 3.5 dB.

IV. Conclussion

3D printing is a very quick and inexpensive way of creating antenna prototypes. However, at THz, more strict requirements on surface quality can become a concern especially when it comes to conductive coating the 3D printed plastic. We outline a smoothing method that can achieve a conductive surface roughness that is limited to 4 μm, which performs at the THz frequencies with minimal roughness loss.

References

[1] M. Liang, J. Wu, X. Yu and H. Xin, "3D printing technology for RF and THz antennas," *2016 International Symposium on Antennas and Propagation (ISAP)*, Okinawa, 2016, pp. 536-537.

[2] H. Yi, S. Qu, K. Ng, C. H. Chan and X. Bai, "3-D Printed Millimeter-Wave and Terahertz Lenses with Fixed and Frequency Scanned Beam," in *IEEE Transactions on Antennas and Propagation*, vol. 64, no. 2, pp. 442-449, Feb. 2016.

[3] M. van der Vorst and J. Gumpinger, "Applicability of 3D printing techniques for compact Ku-band medium/high-gain antennas," *2016 10th European Conference on Antennas and Propagation (EuCAP)*, Davos, 2016, pp. 1-4.

[4] P. Juyal, S. Adibelli, and A. Zajic, "THz near field focusing using Cassegranian configuration for EM side-channel detection," *2018 IEEE AP-S Symposium on Antennas and Propagation and URSI CNC/USNC*, Boston, USA, July 8-13, 2018.

[5] S. Sinton and Y. Rahmat-Samii, "Random surface error effects on offset cylindrical reflector antennas," in *IEEE Transactions on Antennas and Propagation*, vol. 51, no. 6, pp. 1331-1337, June 2003.

[6] C. A. Balanis, *Antenna Theory: Analysis and Design*. New York, NY, USA: Wiley, 2012.

[7] CST, Darmstadt, Germany, 2017. Available: https://www.cst.com/.

[8] M. Mrnka, "Random gaussian rough surfaces for full-wave electromagnetic simulations," *2017 Conference on Microwave Techniques (COMITE)*, Brno, 2017, pp. 1-4. M. Mrnka, "Random gaussian rough surfaces for full-wave electromagnetic simulations," *2017 Conference on Microwave Techniques (COMITE)*, Brno, 2017, pp. 1-4.

[9] "FORMIGA P 110 Velocis." [Online]. Available: https://www.eos.info/systems_solutions/plastic/systems_equipment/formiga_p_110. [Accessed: 09-Jan-2019].

[10] J. Ruze, "Antenna tolerance theory—A review," in *Proceedings of the IEEE*, vol. 54, no. 4, pp. 633-640, April 1966.