İSTANBUL UNIVERSITY CERRAHPAŞA

RESEARCH ARTICLE

Electrica 2020; 20(2): 177-181

Development of 15-dB Gain Conical Horn Antenna Using 3D Printing Technology

Murat Can Karakoç, **Asaf Behzat Şahin**

Department of Electrical and Electronic Engineering, Ankara Yıldırım Beyazıt University Faculty of Engineering and Natural Sciences, Ankara, Turkey

Cite this article as: . M. M. Karakoç, A.B. Şahin. Development of 15-dB Gain Conical Horn Antenna Using 3D Printing Technology. *Electrica*, 2020; 20(2): 177-181.

ABSTRACT

In this research, we manufactured a commercially available standard-gain conical horn antenna by using a three-dimensional (3D) printer. Such antennas are expensive, and they take very long to deliver; therefore, it is desirable to fabricate antennas using the 3D printing technique. Hence, we designed the WR-15 conical horn antenna using SolidWorks. To fabricate this antenna, we used a 3D printer with polylactic acid material. The inner surface of the antenna was made conductive by coating it with copper and spray painting it with silver. We investigated the performance of the horn antennas. The scattering parameters of the fabricated antenna painted in silver were compared with the theoretical scattering results and the scattering parameters taken from commercially available antennas.

Keywords: 3 dimensional printing, conical horn antenna, millimeter wave

Introduction

In recent years, many tools have been introduced for the evaluation and manufacturing process of products. Three-dimensional (3D) printers play an important role for the development and production of different kinds of equipment. These printers are used in many fields, such as medicine, aerospace, and telecommunications. For example, NASA astronauts started to use 3D printers in space to assist in producing parts and tools in zero gravity. Moreover, companies, such as General Electric, Airbus, and Rolls-Royce, have also been investing to develop products using 3D technology; 3D printers are being increasingly used for the fabrication of antennas and waveguides in the fields of radio frequency (RF) and wireless communications. Researchers have started finding their own way of producing products using 3D printers because RF products are expensive and have a long delivery time. These RF components are modeled using SolidWorks computer-aided design tools. Then, they are printed using a polylactic acid (PLA) filament, which is a thermoplastic aliphatic polyester derived from renewable resources and is used in 3D printers.

After the manufacturing process, conductive materials are used for the coating. This coating process is performed in different ways, such as painting, electroplating, and taping with copper or silver. The performance of both copper tape and Caswell copper spray coating have been compared in [1]. Pyramidal standard-gain horn antennas operating at 28 GHz are manufactured and coated with these conductive materials [1]. Moreover, this commercially available antenna was simulated by using a high-frequency structure simulator, and these simulation results were compared with the experimental measurements. In addition to the radiation pattern of simulation and the experimentally measured results, the return loss parameters S_{11} for the copper paint and copper tape were also supported [1]. These 3D printed antennas can also be used for some radar applications. Snow-monitoring pulsed radar systems use 3D-printed double-ridge horn antennas [2]. The antenna and waveguide were produced separately to provide effective coverings for the inner areas of the antenna and waveguide [2]. Furthermore, each section was also divided into two parts. Then, each part was separately painted with silver spray, and the parts were combined [2, 3]. Unlike the case for common structures in 3D printing horn antenna technologies, printed circuit board feed was used to deliver the input signal into the waveguide [2]. In this research, we provide the measured and simulated radiation patterns and gain. We also provide the measured and simulated antenna efficiencies between 1 GHz and 8 GHz [2].

Different plastic materials can be used to print the RF components. To observe the performance of various plastic materials, we fabricated a type of pyramidal horn antenna working

Corresponding Author:
Murat Can Karakoç

E-mail:
mkarakoc@ybu.edu.tr

Received: 21.02.2020

Accepted: 27.04.2020

DOI: 10.5152/electrica.2020.19094

between 7.5 GHz and 18 GHz by using three plastics: acrylonitrile butadiene styrene, PLA, and Vero [3]. These three types of antennas were experimentally tested using three metallization processes: vacuum metallization, electroplating, and conductive paint; then, the performance of each antenna was investigated [3]. The most resistive coating process was conductive painting, and this was followed by vacuum metallizing and electroplating (in ohms per cm) [3].

Although many ongoing studies have focused on applications with less than 60 GHz frequency, certain designs work at 60 GHz [4-6]. Unlike this study, which produces a horn antenna using PLA material, previous studies have investigated metallic 3D printed horn antennas [4-6]. Plastic-based 3D printing of antennas is more effective than the laser beam melting process in terms of cost effectiveness and fabrication.

In this paper, we use a 3D model with manufacturing details that describe the physical properties and covering process of the material. Section III gives the measurement results as compared with the theoretical and original antenna results. The conclusions are presented in the last section.

3D Model, Manufacturing Details, and Measurement Setup

3D Model and Manufacturing Details

The standard-gain horn antenna that we designed is based on the antenna model SAC-1533-15-S2 produced by SAGE Millimeter Inc. [7]. The geometry of the antenna is shown in Figure 1, where B and D indicate the inner and outer diameters of the horn antenna, respectively. C is the WR-15 waveguide aperture size, and F is the length of the waveguide. A is the holder dimension used for connecting the antenna with the other equipment. Table 1 gives the detailed dimensions of each part of the labeled antenna shown in Figure 1.

The designed antenna has been saved as a standard template library (STL) file. The STL file was imported into a 3D printing system, and the horns were fabricated using a PLA material

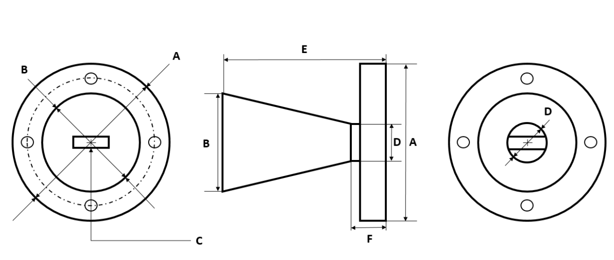


Figure 1. Shape of the antenna

provided by RAISE3D. The permittivity and loss tangent of the material varied according to the E and H directions [8]. The permittivities of the E and H directions were 2.74 and 2.83 at 60 GHz, respectively. The tangent losses of the E and H directions were 0.0141 and 0.0161, respectively, at 60 GHz [8].

In the first part of the plating process, the inner surface of the 3D printed horn antenna was coated with copper. This coating operation was used with electroplating. Electric currents were used in the electroplating coating process in which the plating metal was transferred to the conductive or nonconductive surfaces [9]. To provide conductivity to nonconductive materials, the surface of the nonconductive material should be coated by processes such as graphite coating, conductive lacquering, electroless plating, or vaporized coating [9]. In this electroplating process, the inner surface of the antenna was first softened with acetone to provide minimum roughness. Then, the inner surface was covered with graphite to make this surface conductive; this graphite covering also ensured that the copper particles inside the copper sulfate ($CuSO_4$) solution could conduct to the graphite coppered surface of the antenna. We dissolved 200 gr $CuSO_4$ in 1 L water in the first part of the solution. Then, 100 mL hydrochloric acid *(HCl)* was added to this solution. To maintain the acidity of the solution, we used *HCl*. Before using *HCl* as an acid in the solution, we used vinegar. However, the conduction of the *Cu* electrons into the graphite surface decreased gradually because of the declining the level of vinegar in the solution. The copper-plated horn antenna is depicted in Figure 2(a). However, the performance of the copper-plated antenna was not satisfactory because of resistivity and other effects related to the roughness. The solution used for the covering operation did not allow the surface to be covered equally with the same thickness because parts of the inner surface, which were covered early with , were prone to be covered with free *Cu* electrons in the solution. At the end, these parts were thicker than most other parts; this could be observed clearly during the plating.

In the second part of the fabrication process, the horn antenna was spray painted with silver. This process started with the same treatment applied for the copper plating, namely, providing signal conductivity throughout the inside surface of the horn antenna without any distortion. Some hardness of the inside surface was eliminated by using acetone. Then, this surface was painted with conductive silver material. After that, the performance of the silver-painted antenna was investigated at 60 GHz. The silver-painted horn antenna is illustrated in Figure 2(b).

Measurement Setup

The parameters of the designed antenna were measured using the setup shown in Figure 3. This measurement setup was com-

Table 1. Dimensions of the antenna

A (mm)	B (mm)	C (mm)	D (mm)	E (mm)	F (mm)
19	10.77	2 × 4	4.4	23.5	9.59

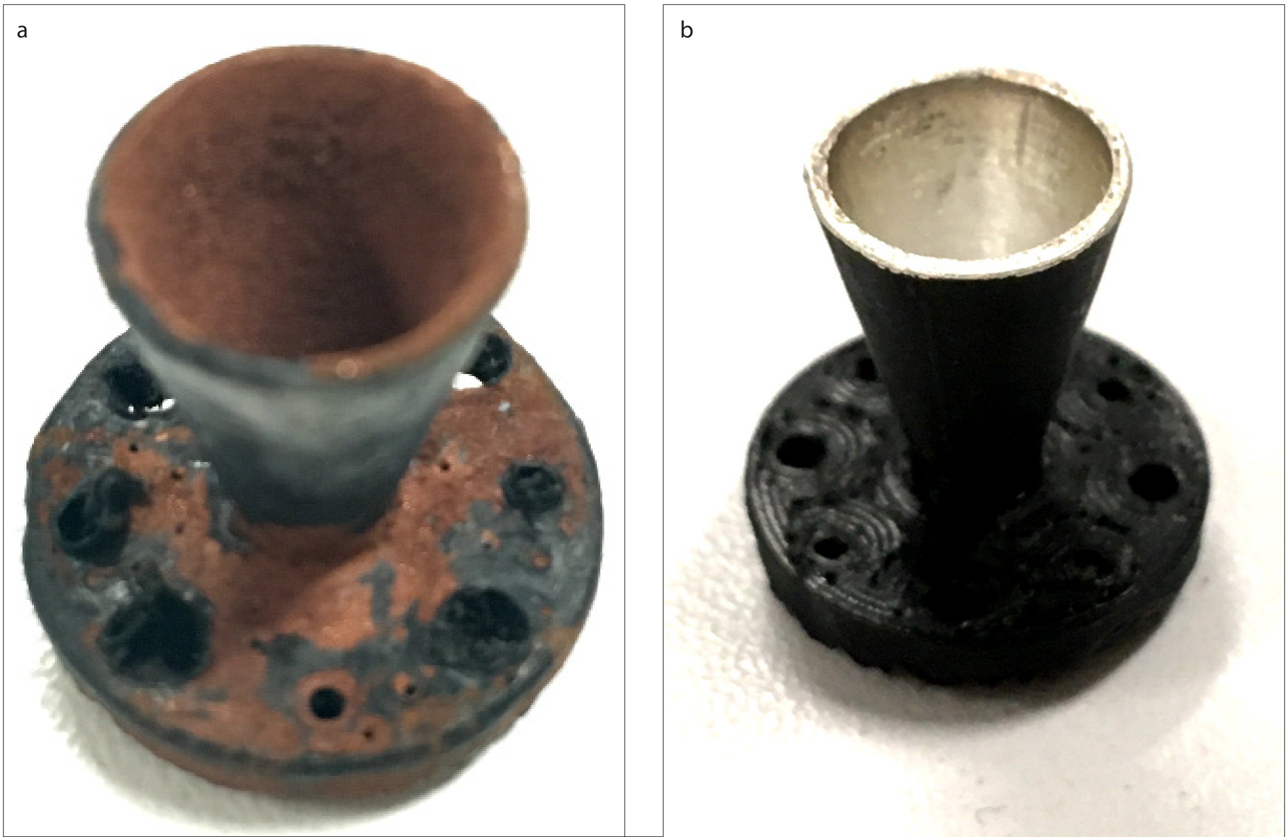


Figure 2. a, b. Copper-coated antenna (a), Silver-painted antenna (b)

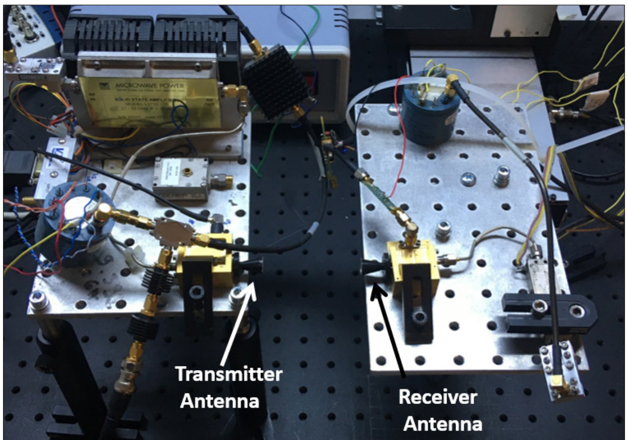


Figure 3. Test setup

posed of a typical transmitter and a receiver structure, which functioned between 50 GHz and 75 GHz. The same antenna was used on both sides of the system. The transmitter part of the system was placed in a fixed position, then the receiver antenna was placed in the far-field region to determine the radiation beam pattern of the antennas; the receiver antenna was placed at a distance further than 20 times the wavelength of the antenna. Then, the receiver antenna was moved in the vertical and horizontal directions for observing the radiation pattern.

Comparison of the Measurement Results

The antenna was originally designed to work between 58 GHz and 68 GHz; the best performance was expected to be observed at approximately 60 GHz. Therefore, the horizontal and vertical propagation tests of the antenna were used at 60 GHz. To make the comparison fair, these values were also compared with the theoretical results [10]. The theoretical and measurement results are interpreted in Figure 3.

The measurement results for the both the propagation directions were also compared with the original antenna parameters given in the datasheet [7]. This comparison is depicted in Figure 4. Although there were some mismatches for the horizontal and vertical polarizations, the general trend was very similar for both the directions.

The efficiency of the antenna was also measured to observe the effectiveness of the 3D printed antenna. To compare the efficiency of our fabricated antenna with that of the silver-painted 3D printed horn antenna, we measured the received power of the pyramidal antenna. The transmitter and receiver antennas were positioned as close as possible, and the received power was measured. The received power was found to be 181 mV_{pp} and 188 mV_{pp} for the pyramidal and conical horn antennas, respectively. Hence, the efficiency was approximately 100% for the silver-painted 3D printed horn antenna (Figure 5).

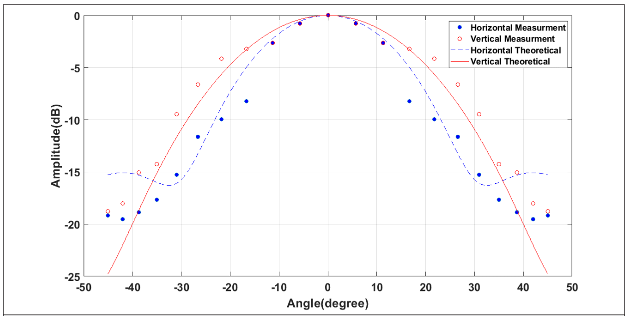


Figure 4. Measurement vs. theoretical results

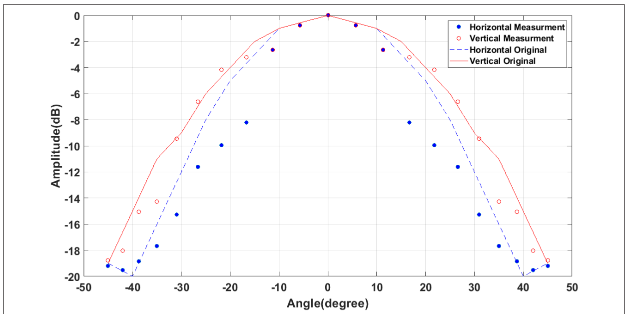


Figure 5. Measurement vs. original results

Conclusion

Researchers have been trying to use antennas as effectively as possible because such equipment are expensive, and they take quite long to deliver. Recent developments in 3D printing technology is quite helpful for manufacturing these materials. We fabricated antennas using PLA with 3D printers. Then, we painted the inner surfaces of these antennas. In our design, we showed that these type of antennas that work in the millimeter and sub-millimeter wave region can be produced by using 3D printing technology. We proved that 3D printed antennas can work efficiently in high frequencies. The theoretical and experimental results were quite close. The original and experimental measurement results also matched substantially. In addition, the efficiency of our proposed antenna was very similar to that of other commercially produced antennas.

Acknowledgements: The authors would like to thank to Fatih Uludağ for his contribution in the manufacturing process of the antenna and thanks to my colleague Ziaoulrahman Sediqi, Abdulrahim Evli and Mustafa Anıl Reşat.

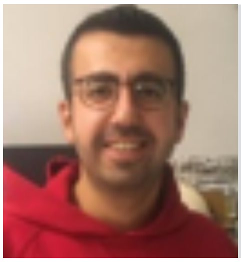
Peer-review: Externally peer-reviewed.

Conflict of Interest: The authors have no conflicts of interest to declare.

Financial Disclosure: The authors declared that this study has received no financial support.

References

1. H. Yao, S. Sharma, R. Henderson, S. Ashrafi, D. MacFarlane, "Ka band 3D printed horn antennas," 2017 Texas Symposium on Wireless and Microwave Circuits and Systems (WMCS), Waco, TX, 2017. [Crossref]
2. V. Midtbøen, K. G. Kjelgård and T. S. Lande, "3D printed horn antenna with PCB microstrip feed for UWB radar applications," 2017 IEEE MTT-S International Microwave Workshop Series on Advanced Materials and Processes for RF and THz Applications (IMWS-AMP), Pavia, 2017. [Crossref]
3. K. V. Hoel, S. Kristoffersen, J. Moen, K. G. Kjelgård and T. S. Lande, "Broadband antenna design using different 3D printing technologies and metallization processes," 2016 10th European Conference on Antennas and Propagation (EuCAP), Location: Davos, 2016. [Crossref]
4. B. Zhang et al., "Metallic 3-D Printed Antennas for Millimeter- and Submillimeter Wave Applications," in IEEE Transactions on Terahertz Science and Technology, Volume: 6, No: 4, Pages: 592-600. [Crossref]
5. B. Zhang, P. Linnér, C. Karnfelt, P. L. Tarn, U. Södervall and H. Zirath, "Attempt of the metallic 3D printing technology for millimeter-wave antenna implementations," 2015 Asia-Pacific Microwave Conference (APMC), Location: Nanjing, Date: 2015. [Crossref]
6. B. Zhang and H. Zirath, "A Metallic 3-D Printed E-Band Radio Front End," in IEEE Microwave and Wireless Components Letters, Volume: 26, No: 5, Pages: 331-333. [Crossref]
7. Available From: URL: https://www.sagemillimeter.com/content/datasheets/SAC-1533-15-S2.pdf, Date of Access: 20th of December, 2019.
8. J. M. Felício, C. A. Fernandes and J. R. Costa, "Complex permittivity and anisotropy measurement of 3D-printed PLA at microwaves and millimeter-waves," 2016 22nd International Conference on Applied Electromagnetics and Communications (ICECOM), Location: Dubrovnik, Date: 2016. [Crossref]
9. Avaliable From: URL: https://www.britannica.com/technology/electroplating, Date of Access: 20th of January, 2019.
10. Balanis, C. Antenna theory. New York: Wiley-Interscience, 2005.



Murat Can received his B.S. degree in Electrical and Electronics Engineering from Eskisehir Osmangazi University, Eskisehir, Turkey in 2015, and the M.S. degree from Ankara Yildirim Beyazit University, Ankara, Turkey in 2018. He currently follows Ph.D. degree at Ankara Yildirim Beyazit University, Ankara, Turkey.

Dr. Sahin received his B.S. degree in Electrical and Electronics Engineering from Middle East Technical University, Ankara, Turkey in 1996, and the M.S. and Ph.D. degrees from University of Southern California, Los Angeles, CA, USA in 1998 and 2003. He worked as a part time consultant on optical systems for several Silicon Valley companies until 2004. He joined the faculty of the Electrical-Electronics Engineering Department of Middle East Technical University in 2004, where he worked as an assistant professor until 2012. He also gave lectures in Air War College, İstanbul and Middle East Technical University Northern Cyprus Campus.
Since 2012, he has been with the Electrical and Electronics Engineering Department of the School of Engineering and Natural Sciences, Ankara Yildirim Beyazit University, Ankara. His major research interests are Fiber Optics, Communication, Quantum Cryptography, Terahertz, Millimeter waves, and Remote Imaging. He has 2 international patents in the field of optical communications, and more than 80 research publications and conference proceedings in various fields. He has participated in more than 40 R&D projects and is currently researcher and principal investigator in projects in the fields of terahertz spectrometry, sub-millimeter wave remote imaging for security, terahertz frequency communication systems development, and free space optical communications.