Satellite Ka-Band additive manufactured antenna

Avinash Sharma, Jeffery Valenti, Alan Githens, Katherine Wolff, Valerie Lehmann
The Johns Hopkins University Applied Physics Laboratory, USA, http://www.jhuapl.edu

***Abstract*— A horn antenna operating from 18 to 31 GHz, for use in a reflector system was designed and fabricated using three methods. The first method used conventional machining from a block of aluminum, the second method used a metal 3D printing process, and the third method used a resin 3D printing process followed by copper electroplating. The antennas were tested in a compact antenna range and the performance between the three were compared. It was seen that the metal 3D printed antenna compared well with the machined antenna over the full frequency range. However, the resin 3D printed and plated antenna resulted in noticeably more loss than the other two antennas at the higher end of the frequency band.**

Keywords—3D printed antenna; additive manufactured antenna; Ka-band antenna

I. Introduction

Additive manufacturing (AM) processes continue to be refined and are being used in more widespread applications, especially in millimeter-wave antennas and in harsh environments [1-4]. The AM process builds up a complicated three-dimensional structure from a digital representation through successive layering of a material. This can be achieved by directly printing with a metal powder using a Selective Laser Melting (SLM) printer or with a resin and using Stereolithography (SLA) followed by an electroplating process.

One of the disadvantages of the metal printing process is the inherent surface roughness in the finished part, which can decrease the overall efficiency of the antenna. To overcome this limitation, an SLA process was implemented. The finished SLA part has a much smoother surface, but does require an additional plating step to function as an antenna.

In this work, a wideband millimeter wave antenna spanning the commercial, military, and government Ka-frequency bands [5] was designed and fabricated using the two AM methods: direct metal printing and resin printing/plating. The antenna was also fabricated using conventional machining. The performance of the antennas was measured in a compact antenna range and the performance was compared.

II. Antenna Design

A quad-ridge horn antenna, shown in Fig. 1a, was designed for this study. The quad-ridge structure achieves wide bandwidth and has small ridged features that make the antenna fabrication challenging. Both the horn flare and ridges have independent exponential tapers. The beamwdith was designed to be near-constant over the 18 to 31 GHz frequency range, making it ideal for use in a reflector antenna system. The simulated boresight gain versus frequency is shown in Fig. 1b. Note that the gain from 18 to 31 GHz changes by just under 1 dB.

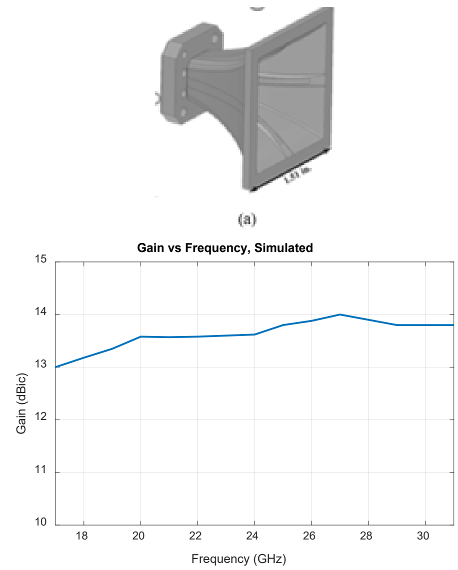


Figure 1. (a) CAD model of the quad ridge horn antenna (b) Simulated gain vs frequency

III. Antenna Fabrication

Three antennas were fabricated, one using a conventional machining process and the other two using additive manufacturing. The first antenna used a 5-axis CNC machine to fabricate the part from a block of 6061 aluminum and is shown in Fig. 2a.

The second antenna was printed with an aluminum powder (RAM2-6061 from Elementum) and a SLM printer. The SLM printer uses a high power laser to selectively melt the aluminum powder. The melted parts fuse together layer-by-layer to form the final antenna structure. This powder was chosen because its final surface finish was smoother than other equivalent powders, such as the AlSi10Mg [6]. However, as can be seen from Fig. 2b, there is still noticeable roughness which can affect the performance at the higher Ka-Band frequencies.

The third antenna used a resin (Rigid 10k) and SLA printer from Formlabs. The SLA process focuses a UV laser onto the photopolymer resin, and draws a shape on its surface. The resin is then photochemically solidified forming a thin layer of the antenna. This process is repeated until the antenna is completely fabricated, as shown in Fig. 2c. Note that the surface roughness is much lower than the metal printed antenna. The part is then plated with copper using an electroless plating process to get uniform coverage, especially over the ridges. This is shown in Fig. 2d.

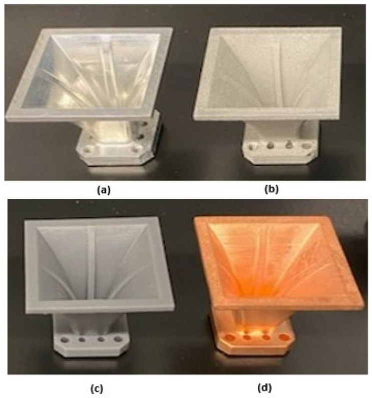


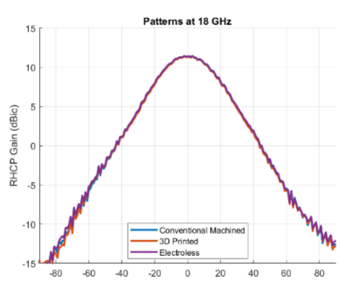
Figure 2. (a) Machined Antenna (b) Metal Printed Antenna (c) Unplated SLA Antenna (d) Plated SLA Antenna

IV. Test Results

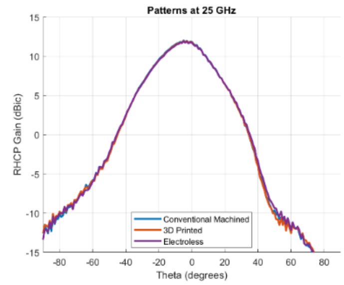
The gain of the three antennas was measured in a compact antenna range. Representative radiation pattern cuts are shown in Fig. 3 for different frequencies. Note that the antenna pattern includes a fixture loss between 1 and 2 dB over the frequency band that is not taken out in the graphs. From Fig. 3a and 3b, the radiation patterns for the three antennas are almost identical, indicating that either of the additive manufactured antennas can be used up to 25 GHz. However, at 31 GHz the SLA antenna is seen to have additional loss, whereas the metal printed antenna still behaves similarly to the conventional antenna, as seen in Fig. 3c. This result was surprising, since the surface roughness of the SLA antenna was negligible. Since the discrepancy was frequency dependent and skewed towards the high frequency, potential causes could be the oxidation layer in the copper, which can be seen in Fig. 2d, or non-uniform plating. These discrepancies will be discussed further at the conference.

V. Summary

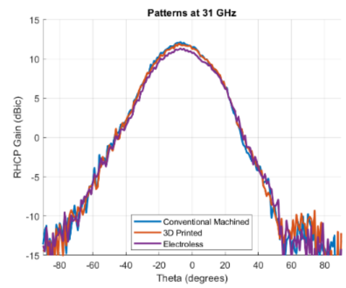
Three antennas were fabricated, two using AM methods and one using conventional machining. The metal AM antenna performed identical to the machined antenna over the full 18 to 31 GHz frequency range. The plated resin antenna performed close to the machined antenna except at the high end of the frequency band. This is believed to be an issue with the plating process, either oxidation or non-uniform plating. However, it was shown that a metal printed antenna can perform as well as a machined antenna up through 31 GHz, improving on previous work [7]



(a)



(b)



(c)

Figure 3. (a) Measured radiation pattern at 18 GHz (b) Measured radiation pattern at 25 GHz (c) Measured radiation pattern at 31 GHz

References

[1] D. Helena, A. Ramos, T. Varum and J. N. Matos, "Antenna Design Using Modern Additive Manufacturing Technology: A Review," in IEEE Access, vol. 8, pp. 177064-177083, 2020, doi:10.1109/ACCESS.2020.3027383G.

[2] G. Addamo et al., "3-D Printing of High-Performance Feed Horns From Ku- to V-Bands," in IEEE Antennas and Wireless Propagation Letters, vol. 17, no. 11, pp. 2036-2040, Nov. 2018, doi:10.1109/LAWP.2018.2859828.

[3] A. Sharma and C. Carpenter, "Additive Manufactured Antenna for NASA's Interstellar Mapping and Acceleration Probe (IMAP)," 2023 United States National Committee of URSI National Radio Science Meeting (USNC-URSI NRSM), Boulder, CO, USA, 2023, pp. 3-4, doi: 10.23919/USNC-URSINRSM57470.2023.10042985.

[4] A. Sharma and J. Ramirez, "3-D printed waveguide-fed X-Band helix antenna array," 2016 IEEE International Symposium on Antennas and Propagation (APSURSI), Fajardo, PR, USA, 2016, pp. 479-480, doi: 10.1109/APS.2016.7695948.

[5] G. Heckler, B. Younes, J. Mitchell, N. Pham, A. Sharma, C. Haskins, E. Weir, "NASA's Wideband Multilingual Terminal Efforts as a Key Building Block for a Future Interoperable Communications Architecture", Ka and Broadband Communications Conference, 27-30 September 2021.

[6] A. Sharma, C. Carpenter and J. Dennison, "Surface roughness effects on additively manufactured aluminum Ka-band waveguide," 2020 IEEE International Symposium on Antennas and Propagation and North American Radio Science Meeting, Montreal, QC, Canada, 2020, pp. 1307-1308, doi: 10.1109/IEEECONF35879.2020.9329866.

[7] A. Sharma, R. K. Stilwell, S. Szczesniak and C. Carpenter, "3D Metal Printed Ka-Band Quad-Ridge Horn Antenna," 2022 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (AP-S/URSI), Denver, CO, USA, 2022, pp. 1986-1987, doi: 10.1109/AP-S/USNC-URSI47032.2022.9886934.