# 3-D Manufactured Antenna Hardware for Space and Ground Systems

Philip Venezia [(1)], Lauren Powell [(1)], Clency Lee-Yow [(1)] & Sudhakar Rao*
(1) Custom Microwave Inc., Longmont Co, 80501, USA, http://www.custommicrowave.com
(*) RaoS Consultants LLC, Rancho Palos Verdes, CA 90275, USA
emails: venezia@custommicrowave.com, lauren@custommicrowave.com, clency@custommicrowave.com, skraoks@yahoo.com

***Abstract*—3D printing technology has made significant advances in recent times enabling feeds and antennas to be manufactured meeting high performance requirements for space and ground applications. This paper presents 3-D manufactured antenna hardware using both metals and plastics. Several antenna designs and hardware are discussed along with their RF performance and photographs.**

***Index Terms*—3-D manufacturing, Antenna Feeds, Radiation Patterns**

## I. INTRODUCTION

Antenna feed assemblies for space applications demand stringent performance meeting thermal, PIM, high power handling, low loss and low cross-pol requirements. The components are typically machined out of Aluminium block and critical components like 4-port junctions are electroformed using copper to achieve tight tolerances required to meet the demanding RF requirements [1-3]. Other manufacturing methods include dip brazing, CNC EDM. These processes are time-consuming and very expensive.

3-D manufacturing technology is more than 10 years old with plastic power and later with metal powder. Initial hardware made out of 3-D manufacturing suffered from tolerances, surface roughness and increased insertion loss compared to machined/electro-formed parts. However, 3-D manufacturing is attractive in terms of fast delivery, low mass, and low cost.

Improved 3-D manufacturing process is explained initially. Several examples of 3-D manufactured feed networks, horns and antennas are described along with the measured RF performance.

## II. 3-D MANUFACTURING

Currently 3-D manufacturing is limited by the machines that can handle sizes of about 11” X 11” X 14”, suitable for Ku, K, & Ka band frequencies. Low frequency feeds are larger and at high frequencies beyond Ka-band the hardware suffers from more losses and surface roughness. Fig. 1 shows the SLM 280 machine using power bed fusion technology. It employs $AlSi_{10}Mg$ alloy as the powder where layers are cut using laser with 80µm spot size and 20µm layer height. Ability to use Al6061 powder and handling sharp corners with < $45^0$ overhangs will be available soon. Larger machine that can handle 19” X 11” X 14” is also available with quad 400 watts laser.


**Fig. 1: SLM 380: 3D metal printing machine**

Some of the components manufactured using 3-D printing are shown in Fig. 2. These include waveguides, filters, T-networks and more complex K/Ka feed networks. The K/Ka network includes a 6-port junction, filters, polarizers, combining T-networks, waveguide ports and horn interface, all designed and manufactured as a single assembly. Custom Microwave Inc. (CMi) has developed and produced multiple feeds in K/Ka bands. The feeds and antennas have very good correlation to simulations. To help with the high-performance feeds, and antennas, CMi has developed proprietary techniques that can achieve better surface finish and accuracy than values advertised by several other 3D printing manufactures.

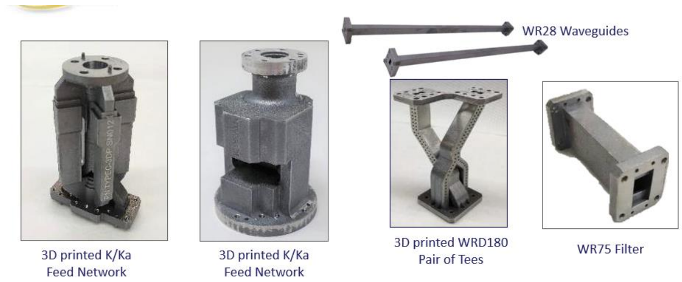



**Fig. 2: Examples of 3-D manufactured feed components**

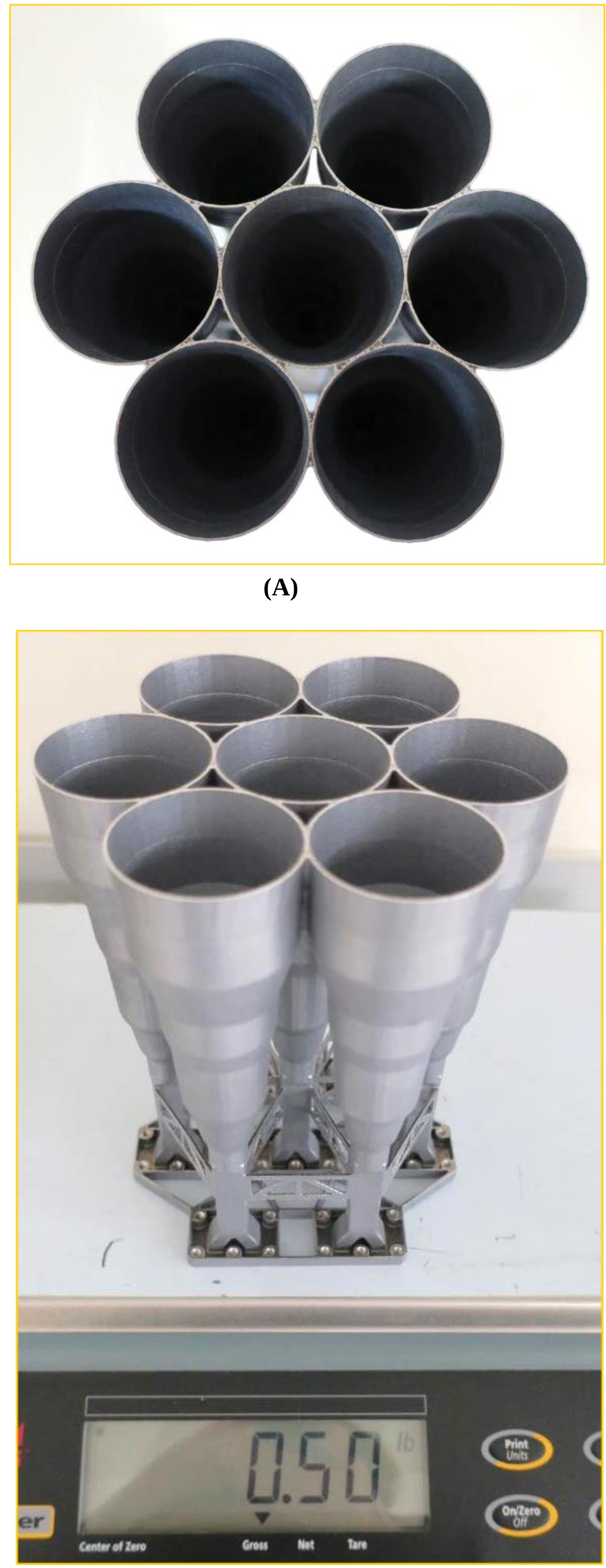
CMi utilizes single- or multi-laser LPBF printers with AlSi10Mg powered. Print parameters are optimized for high dimensional accuracy and low surface roughness. Process and material traceability is maintained through a AS-9100-driven QMS. After printing, AlSi10Mg parts are cleaned of excess powder and heat-treated. Flange faces are machined on CNC mills to a defined flatness and hole patterns were drilled. Parts then proceeded to testing or received additional surface enhancements. CMI has the in-house capability to perform advanced surface finishing techniques that improve internal surface finish and RF performance. These capabilities include chemical smoothing and autocatalytic metal deposition.

CMI qualifies additive manufacturing processes through controlled, documented procedures and analytical testing. After determining the optimal printing parameters for a material and application, the parameters are locked-in, and multiple sets of coupons are produced. Tensile properties, including A-basis levels, of vertically and horizontally printed coupons are measured and calculated. Material density is measured optically and with CT scanning.

.

## III. Examples of 3-D printed antennas and performance

A dual-band (K/Ka) horn cluster including feed-networks for each of the seven elements manufactured with thin walls using 3-D printer is shown in Fig.3. The horns employ multi-mode horns with slope-discontinuities to generate required higher order TE1n modes to achieve high efficiency of about 90%. The feed network includes a transition, polarizer and two orthogonal LHCP and RHCP ports. The overall mass is 0.5 lbs. Measured return loss of the feeds are compared with simulations at K-band in Fig. 4 and at Ka-band in Fig. 5. A good correlation is achieved between measured and simulated values. Return loss is better than 22 dB at K-band and better than 21 dB at Ka-band. Insertion loss is less than 0.4 dB at both bands.




**(B)**

**Fig. 3: 3-D manufactured K/Ka band 7-element feed cluster (A) top view (B) side view**

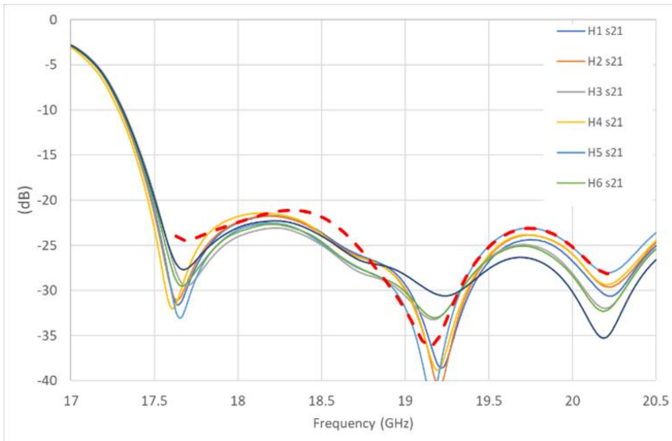



**Fig. 4: Measured input match compared to simulations at K-band frequencies**

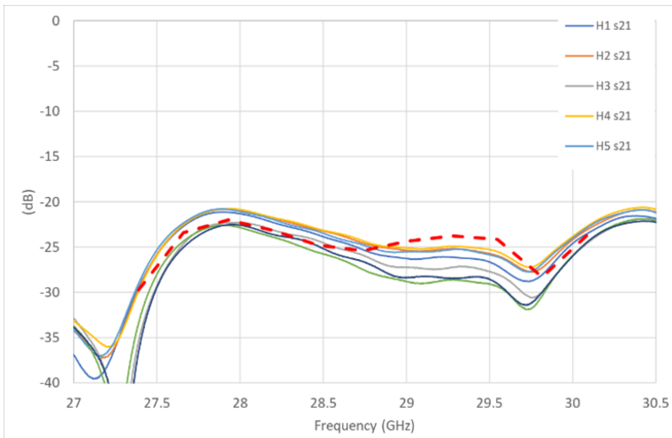



**Fig. 5: Measured input match compared to simulations at Ka-band frequencies**

A tri-band feed cluster of four Ku band horns and a K/Ka band feed realized using 3-D printing is shown in Fig. 6 as manufactured and finished assembly after post processing and plating is shown in Fig. 7. Measured return loss at Ku band is shown in Fig. 8 and compared with simulations. Input match is better than 25 dB over the band. Agreement between measured and simulations is reasonable even with tolerances associated with 3-D printing. Isolation between the RHCP and LHCP ports is shown in Fig. 9 with good agreement between measured and simulated values. Isolation between the ports is better than 27 dB. The tri-band feed assembly has been designed, manufactured, and tested in less than a week. The axial ratio of the four Ku-band feeds has been measured and compared with simulations and the results are shown in Fig. 10. The measured axial ratio is less than 0.17 dB over the frequency band. This demonstrates that 3-D printing is a viable manufacturing method up to Ka-band frequencies achieving high performance while getting benefits of quick turn-around, low mass and less cost.

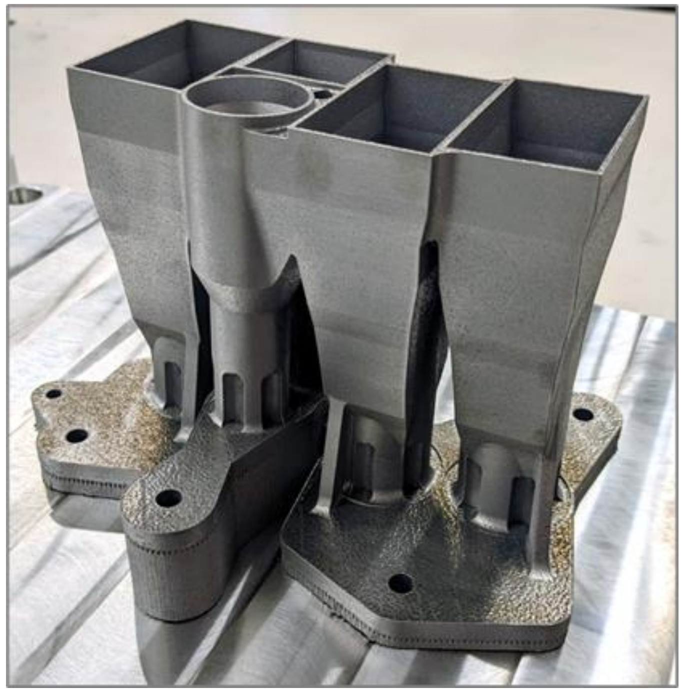


**Fig. 6: Tri-band feed cluster manufactured using 3-D printing (as manufactured)**

**Fig. 7: Tri-band feed cluster manufactured using 3-D printing (after post-processing)**

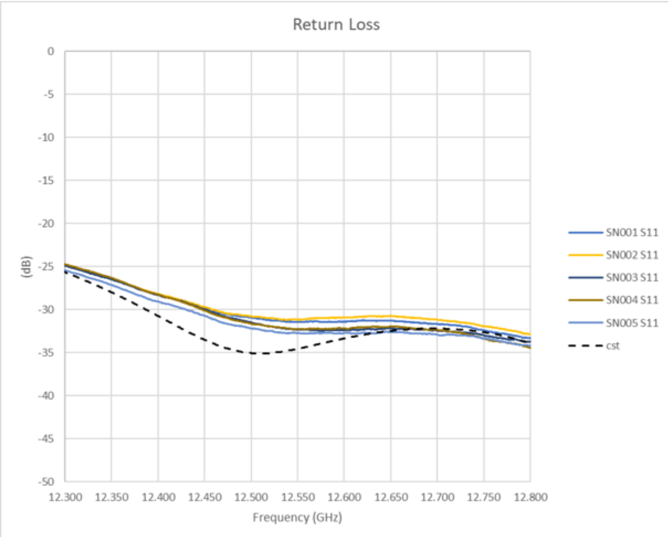



**Fig. 8: Measured input match compared to simulations at Ku-band frequencies of the tri-band feed cluster.**

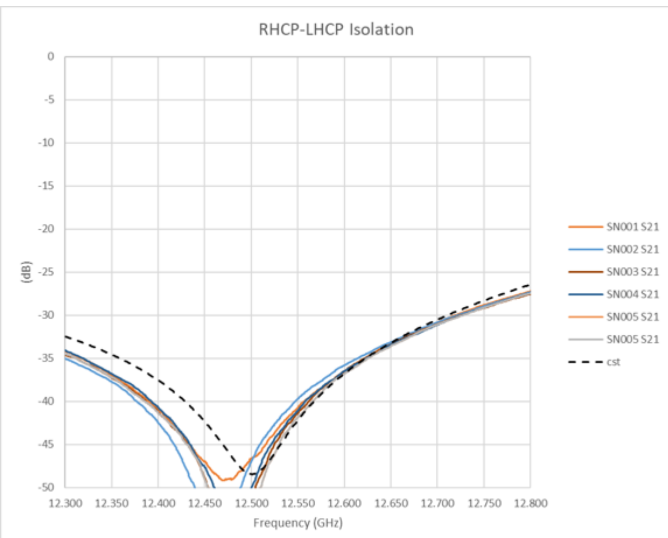



**Fig. 9: Measured isolation between RHCP and LHCP ports compared to simulations at Ku-band frequencies of the tri-band feed cluster.**

Fig. 11 shows a 11” X 13” dichroic plate printed using SLA (stereo lithography) engineered plastic and Fig. 12 shows the dichroic plate after copper plating. Another hardware manufactured using 3-D printed plastic and post-processed using copper plating is a Ku-band horn as shown in Fig. 13. Also, the inside surface can be plated using silver or gold to improve surface conductivity and surface finish to lower the insertion loss as illustrated in Fig. 14.

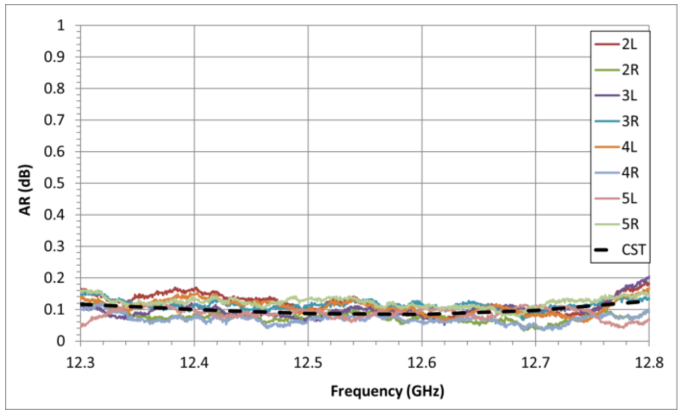



**Fig. 10: Measured axial ratio compared to CST simulations at Ku-band frequencies of the tri-band feed cluster.**

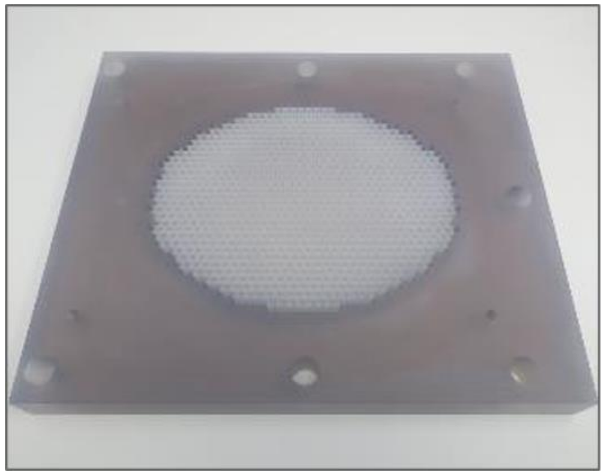


**Fig. 11: Dichroic plate manufactured using SLA engineered plastic.**

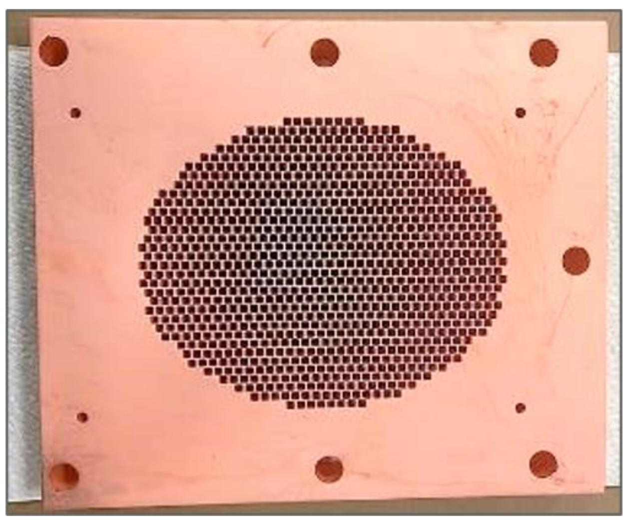


**Fig. 12: Dichroic plate of Fig 11 after post processing using copper plating**

**Fig. 13: Ku-band horn manufactured using copper plated plastic (Formlabs)**

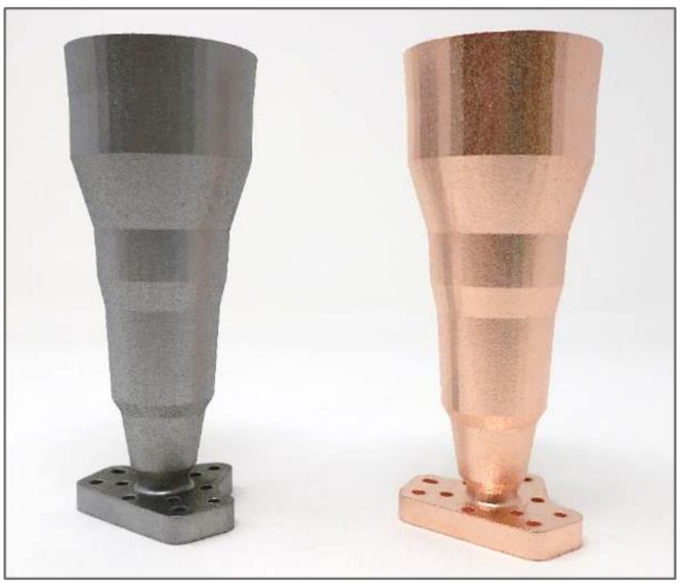


**Fig. 14: Ku-band horn manufactured using gold plating (inside) to improve surface conductivity to achieve lower losses**

## IV SUMMARY & CONCLUSIONS

This paper discusses recent advances in manufacturing of high precision feed assemblies and other antenna components using 3-D printed technology by using metal compound or dielectric. Significant benefits can be achieved in terms of quick production, lower mass and lower cost. Space qualification of K/Ka band feed assemblies has been completed and some of the hardware will soon be flown in space. Future developments include improved metal powder that replicated Al 6061 properties so that post-processing could be minimized.

## REFERENCES


[1] C. Lee-Yow et al, "Handbook of Reflector Antennas and Feed Systems – Applications of Reflectors", , Chapter 7, Vol. III, edited by S. Rao, L. Shafai & S. Sharma, Artech House Publishers, 2013

[2] "Horn antenna synyjesis CAD tool", product feature, Microwave Journal, Vol. 52, No. 3, March 2008

[3] L. J. Durney, "Electroplating Engineering Handbook", Chapman & Hall, London, 1996