JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

Mechanical Performance and Surface Control of Additively Manufactured Aluminum Hardware

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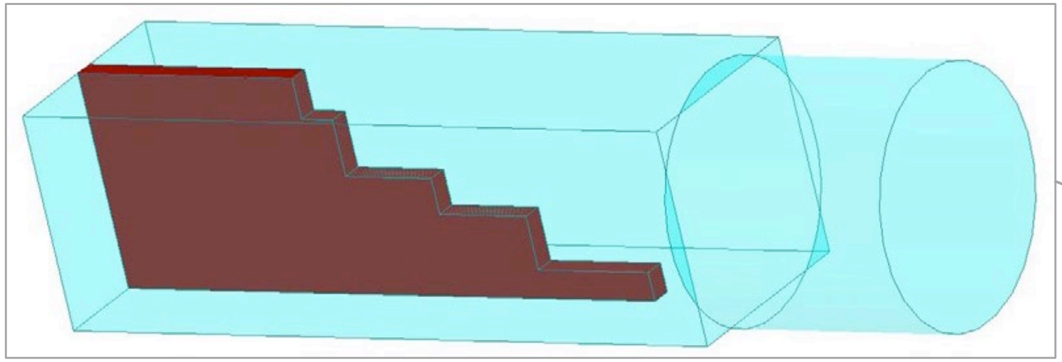
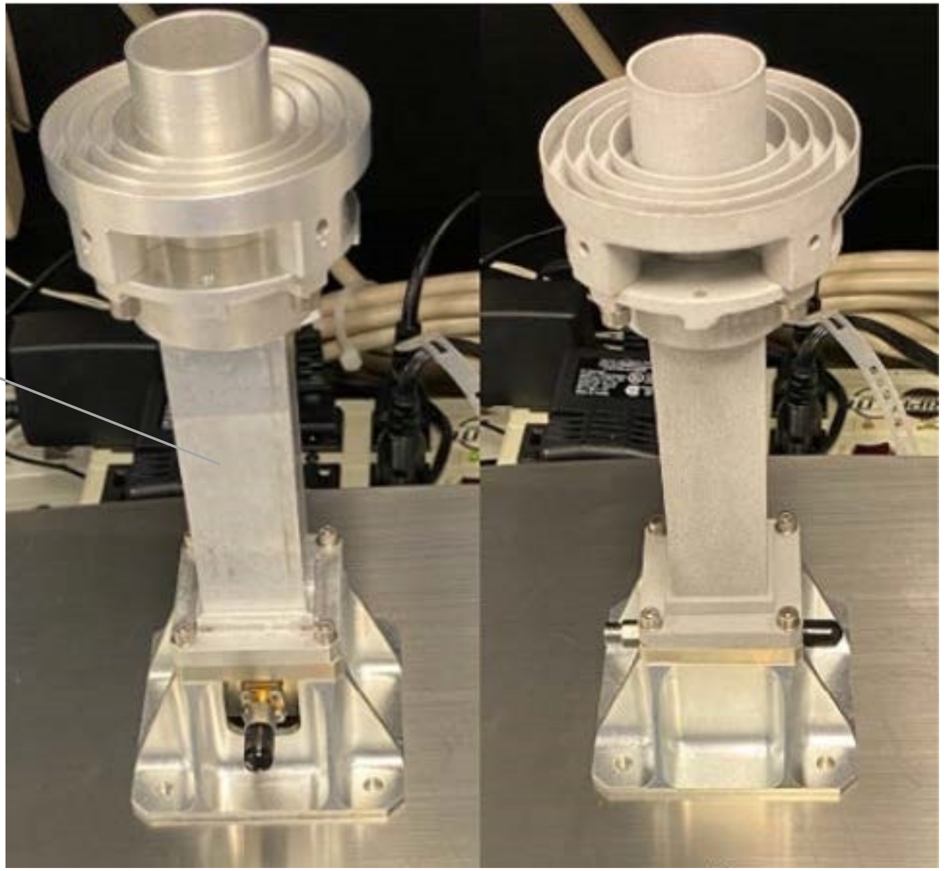
Additive manufacturing (AM) is an attractive process for complex geometries and can enable novel radiofrequency (RF) applications.



The internal stepped geometry of a septum polarizer is challenging to fabricate using traditional machining



Machined and Dip Brazed Aluminum

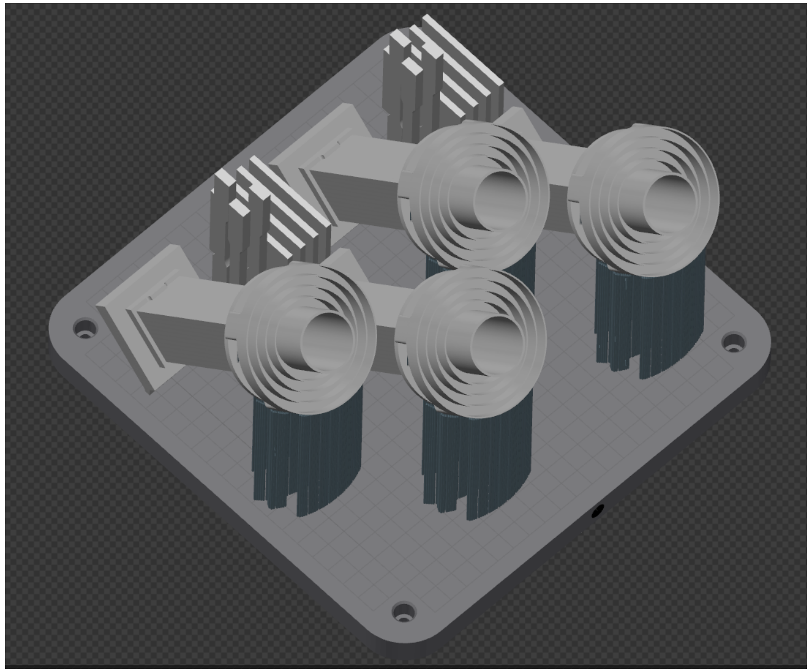
AM Aluminum

References:

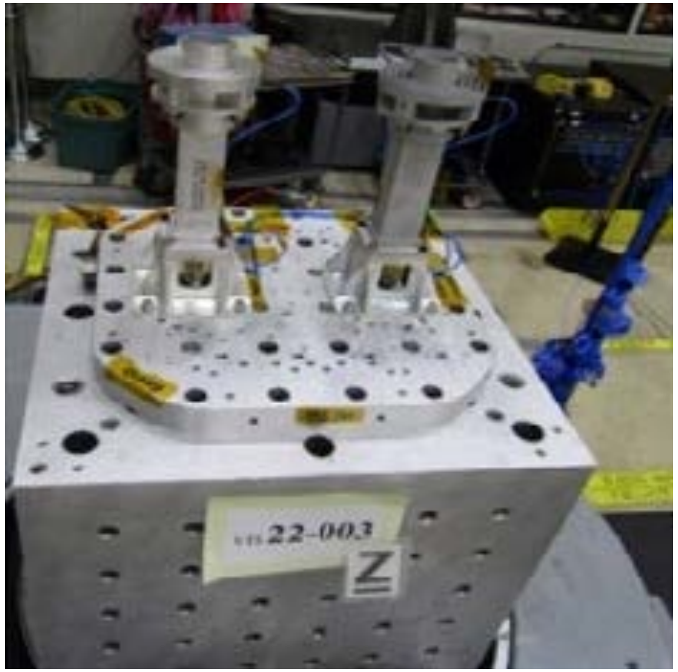
A. Sharma and C. Carpenter, 2023 USNC-URSI NRSM (2023)

A. Sharma, 2021 IEEE APS/URSI (2021)

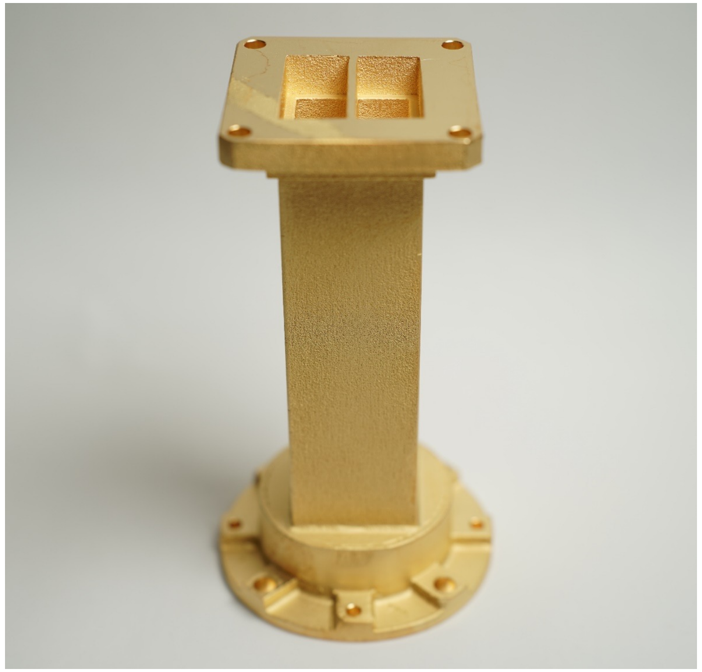
Use of AM for spaceflight must ensure 1) mechanical properties are sound and 2) the surface is sufficiently controlled for contamination.



Use of lot-specific witness samples helps validate mechanical properties



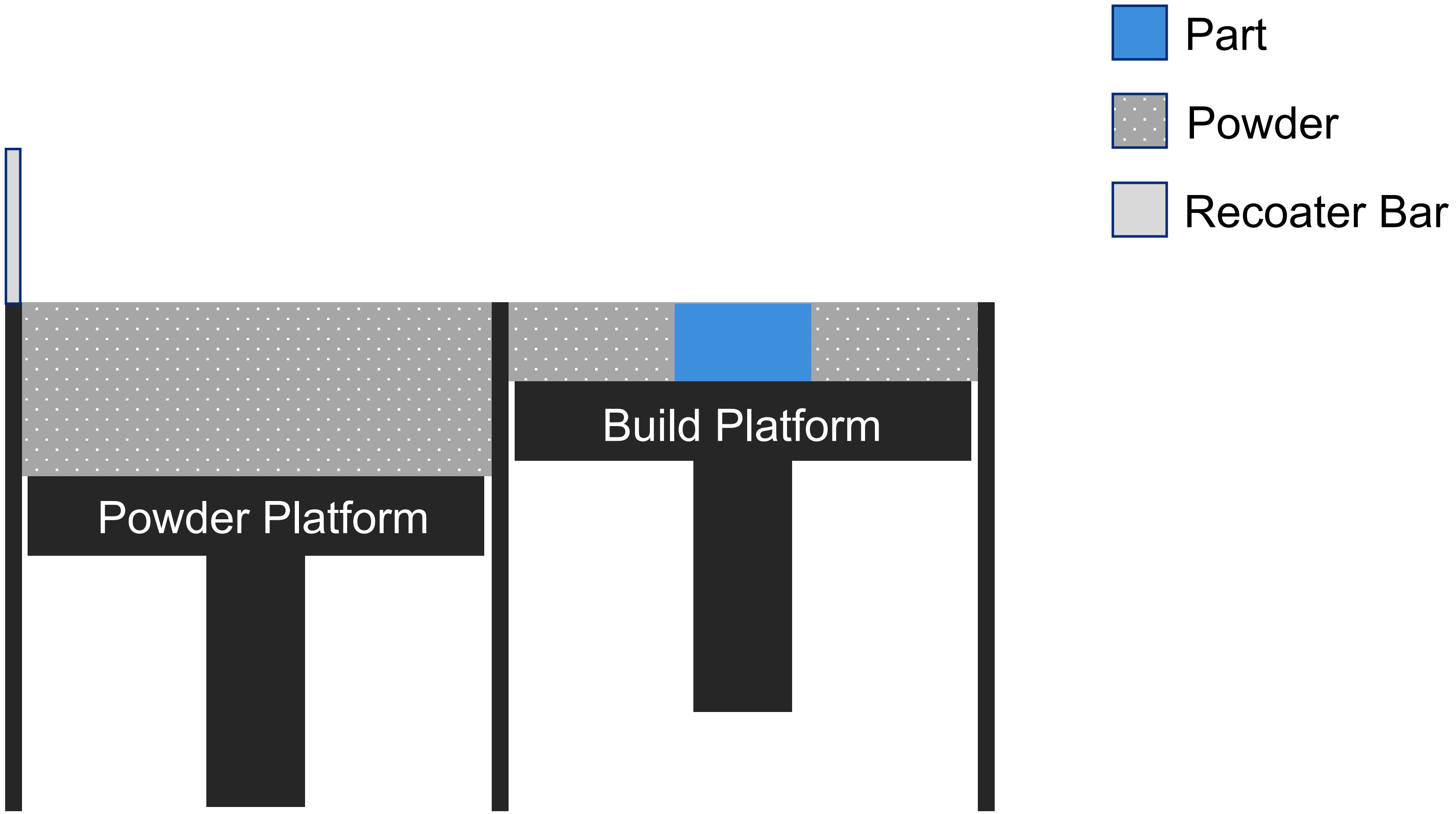
Vibration testing of prototype and flight builds serves as a proof test for mechanical integrity



Development of a plating process addresses particulate control concerns

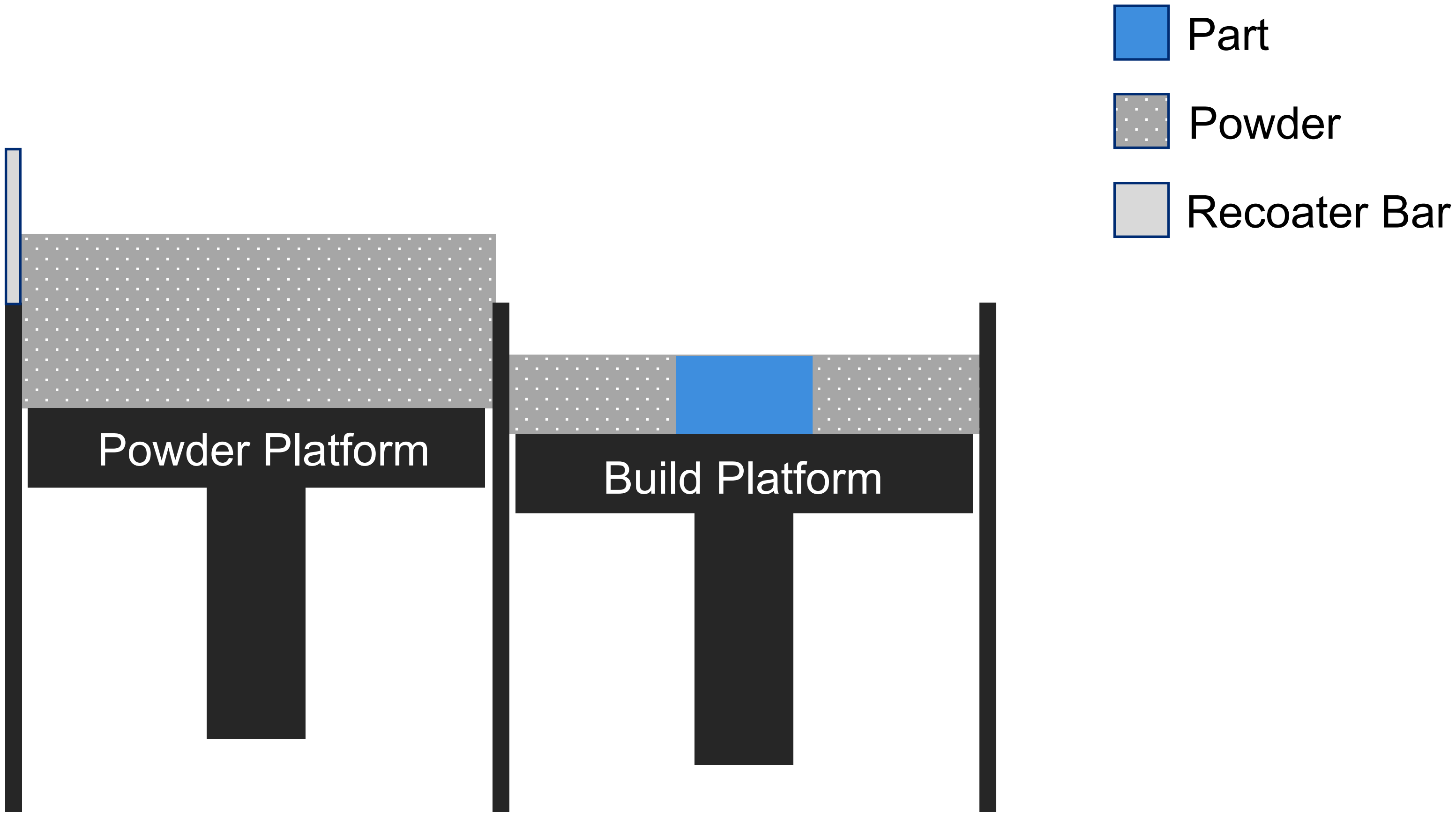
Laser-powder bed fusion (L-PBF) was selected as the AM process due to its maturity and demonstrated quality of built hardware.

Hardware is built inside a bed of powder in which the height of the bed is controlled on a moving platform.



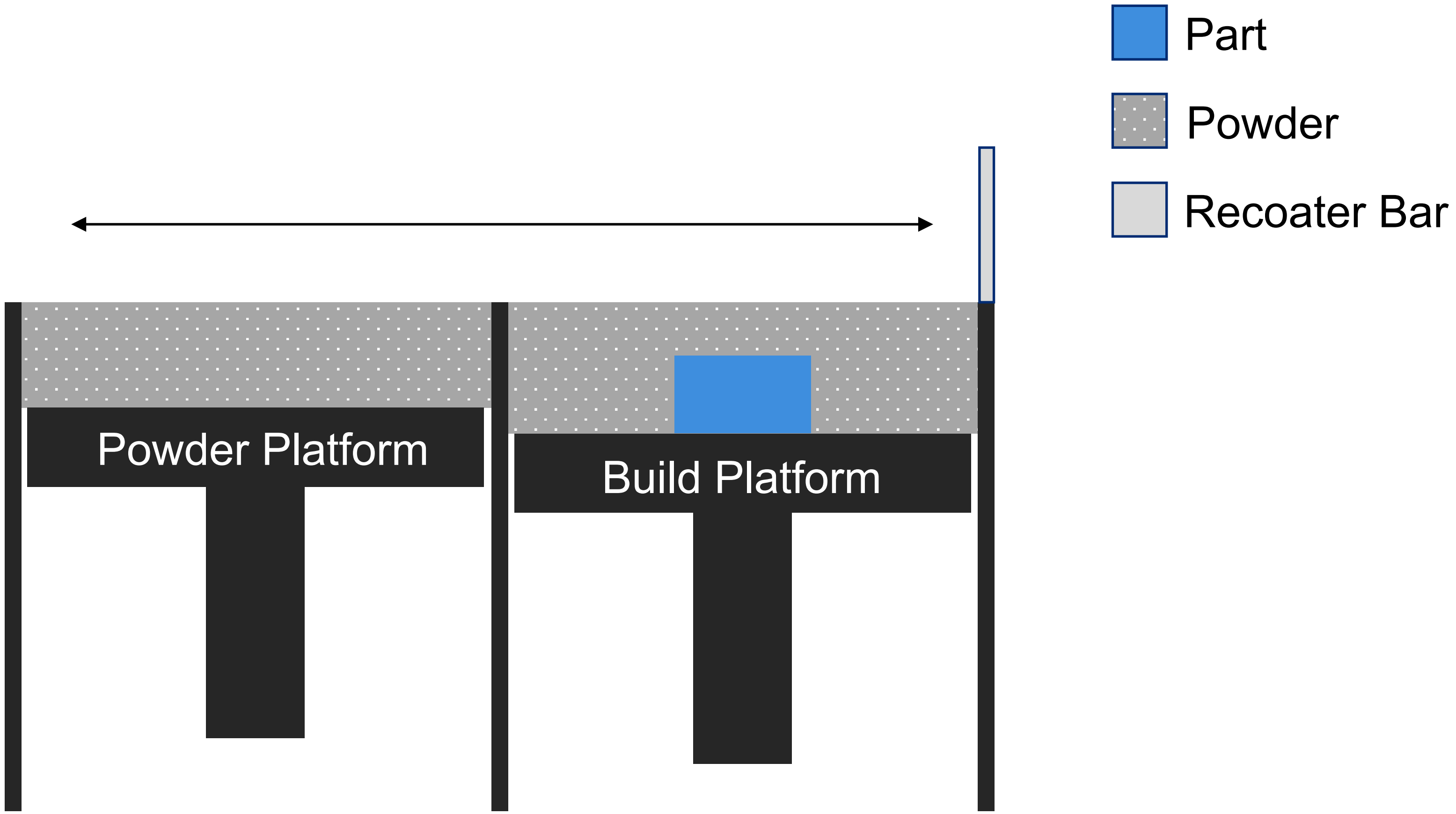
Laser-powder bed fusion (L-PBF) was selected as the AM process due to its maturity and demonstrated quality of built hardware.

To build a layer of the part, the build platform lowers and the powder platform is raised.



Laser-powder bed fusion (L-PBF) was selected as the AM process due to its maturity and demonstrated quality of built hardware.

The recoater bar is swept across the build platform surface to fill the bed with powder.



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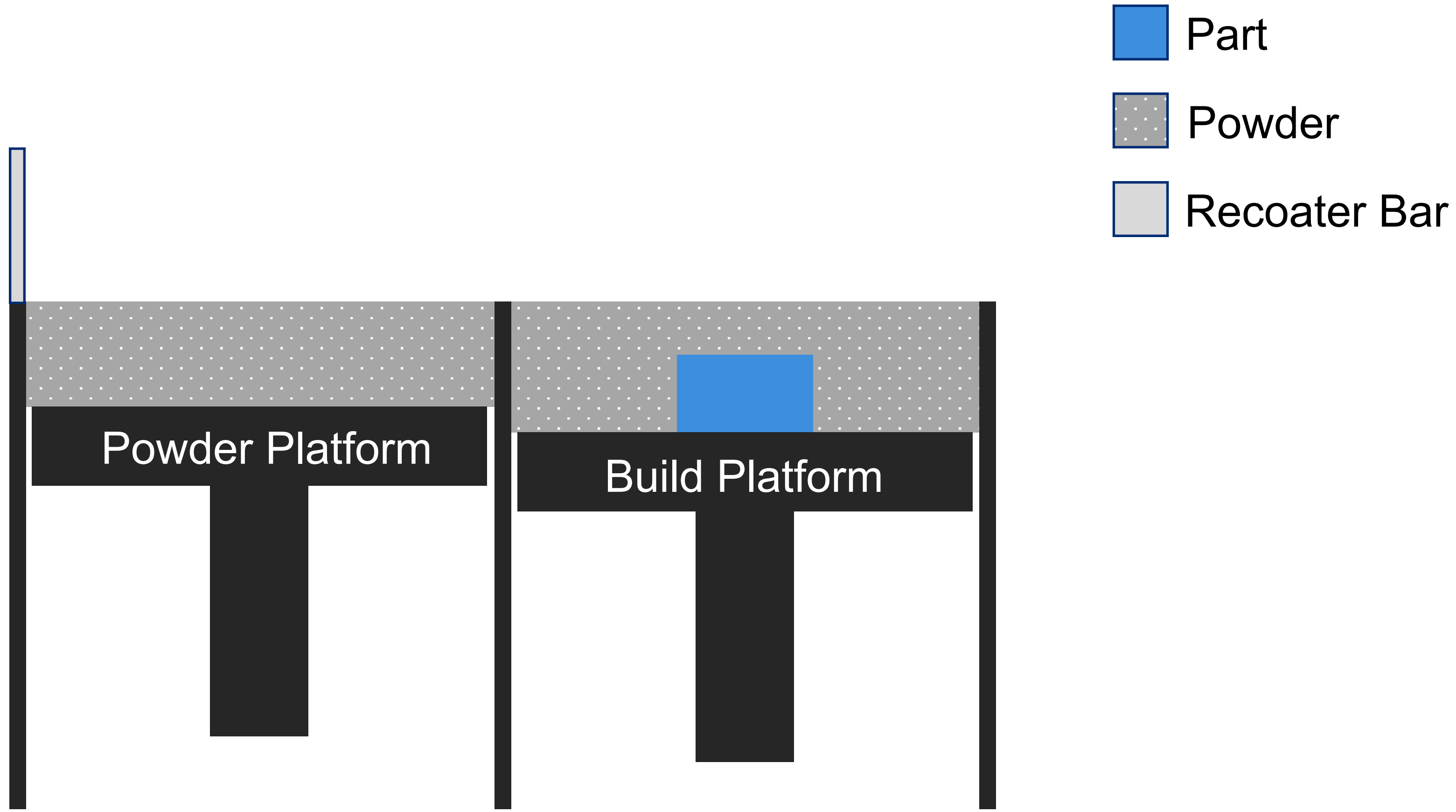
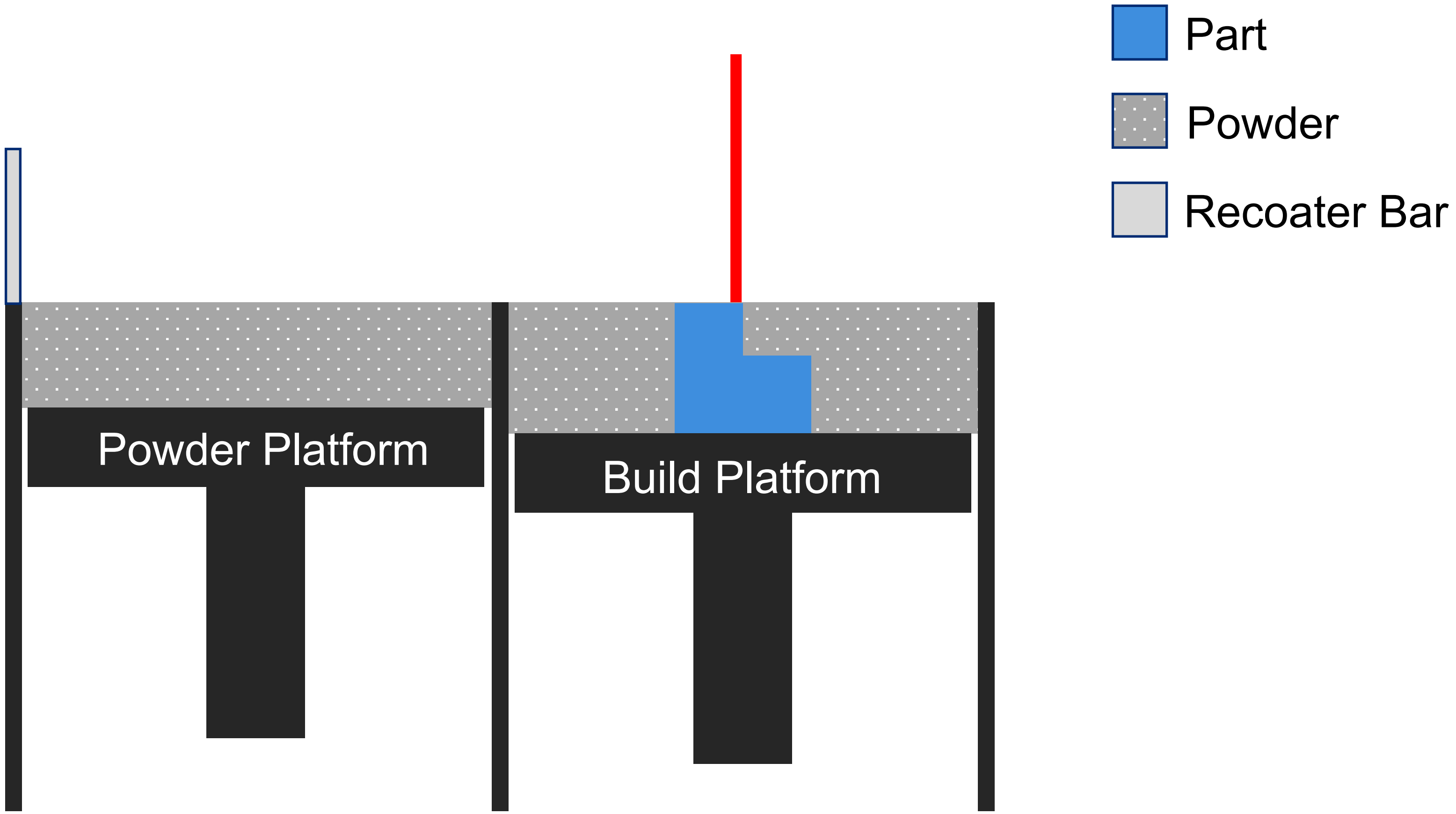


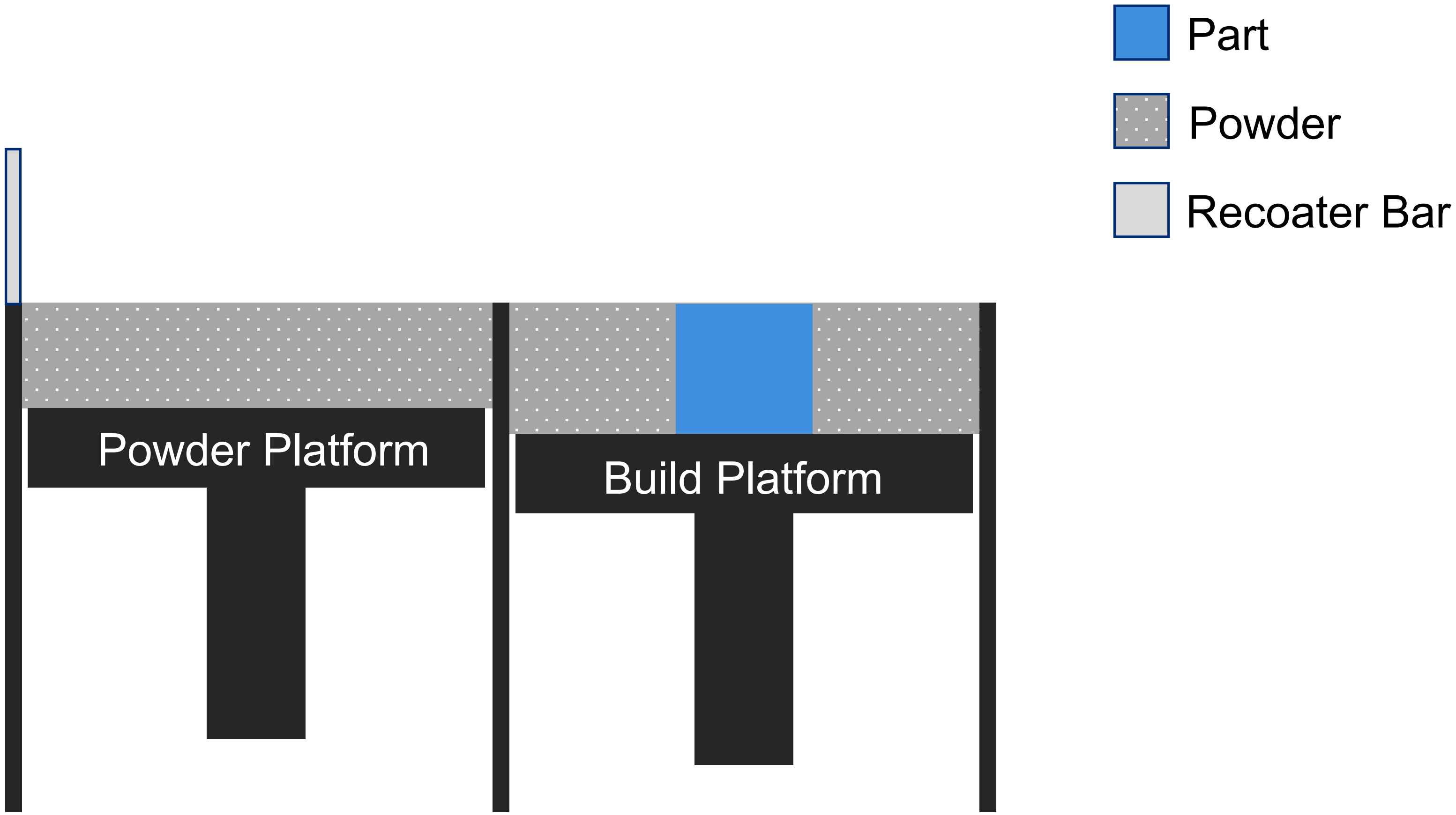
Laser-powder bed fusion (L-PBF) was selected as the AM process due to its maturity and demonstrated quality of built hardware.

A laser is rastered across the surface to weld localized areas of the bed, creating a continuous part.

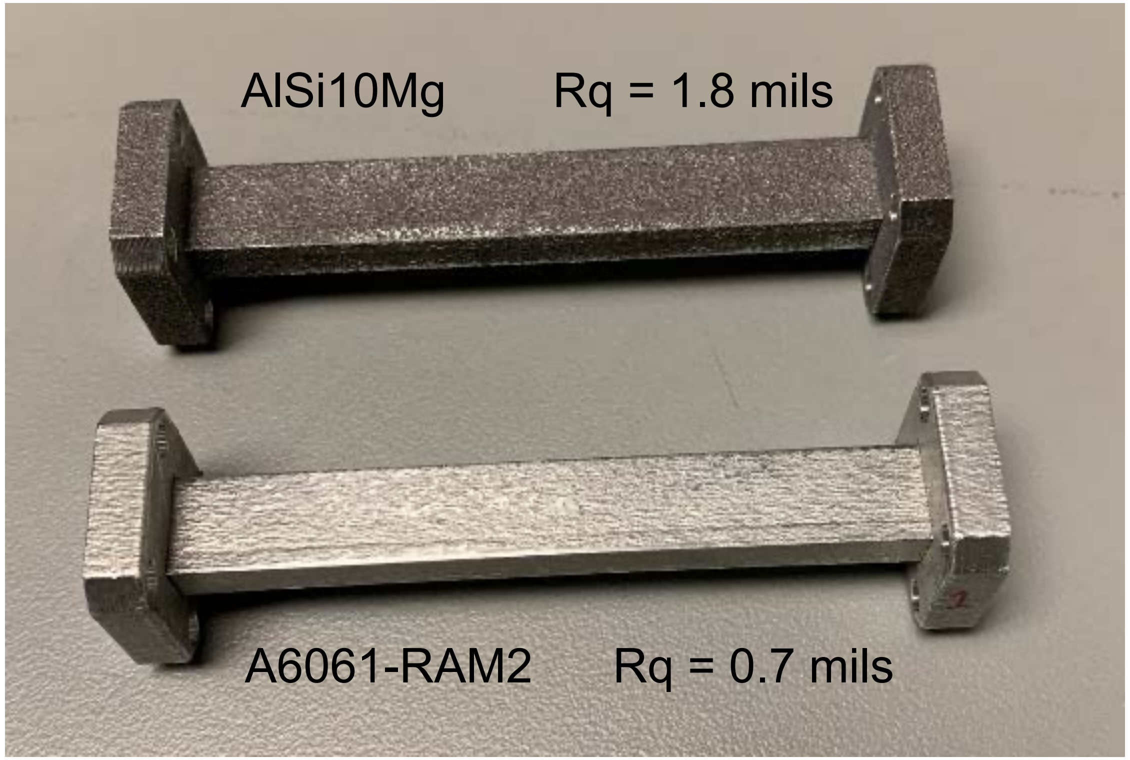


Laser-powder bed fusion (L-PBF) was selected as the AM process due to its maturity and demonstrated quality of built hardware.

The process is completed layer by layer until the desired part is created.



A6061-RAM2 powder was selected for development of a low gain antenna for its improved surface roughness over AlSi10Mg.



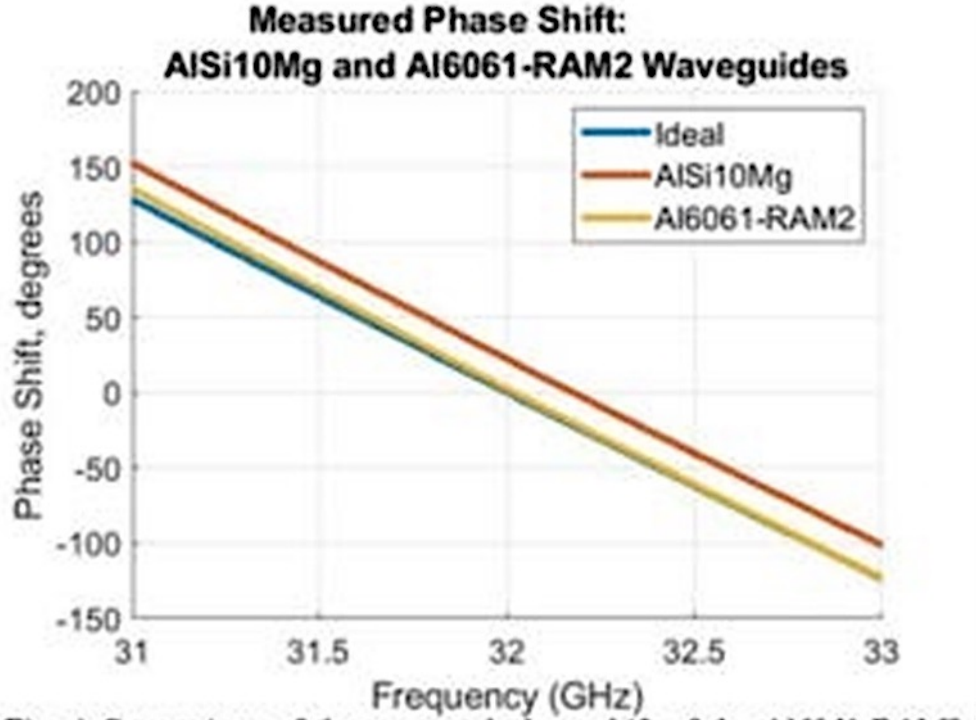


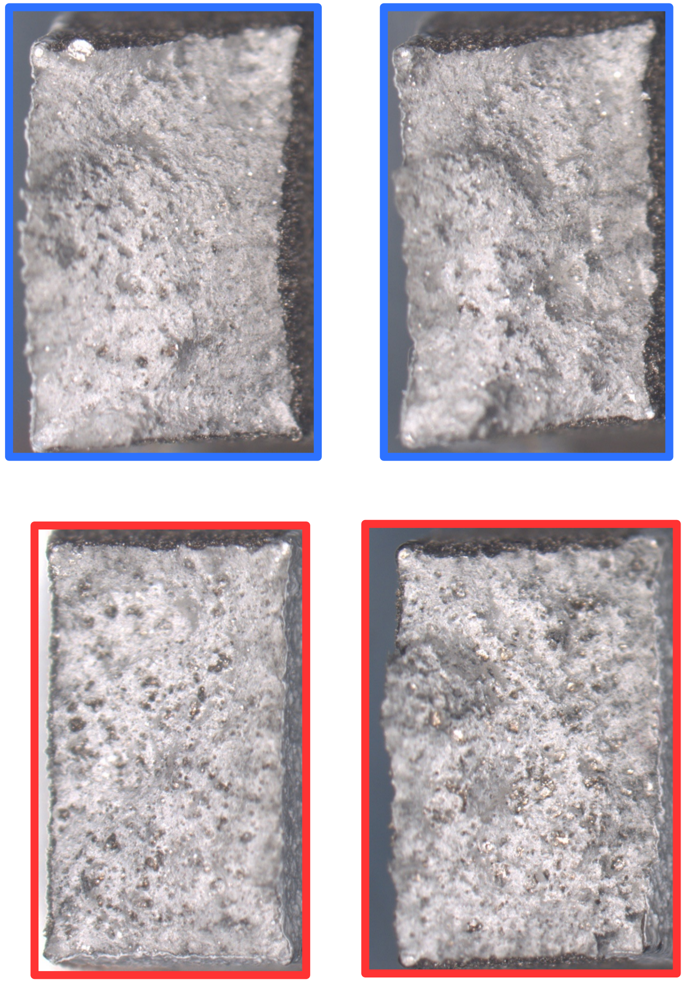
Fig. 4 Comparison of the measured phase shift of the Al6061-RAM2, AlSiMg10 and the ideal response simulated in HFSS

Reference: A. Sharma, C. Carpenter and J. Dennison, 2020 IEEE AP-S/URSI (2020)

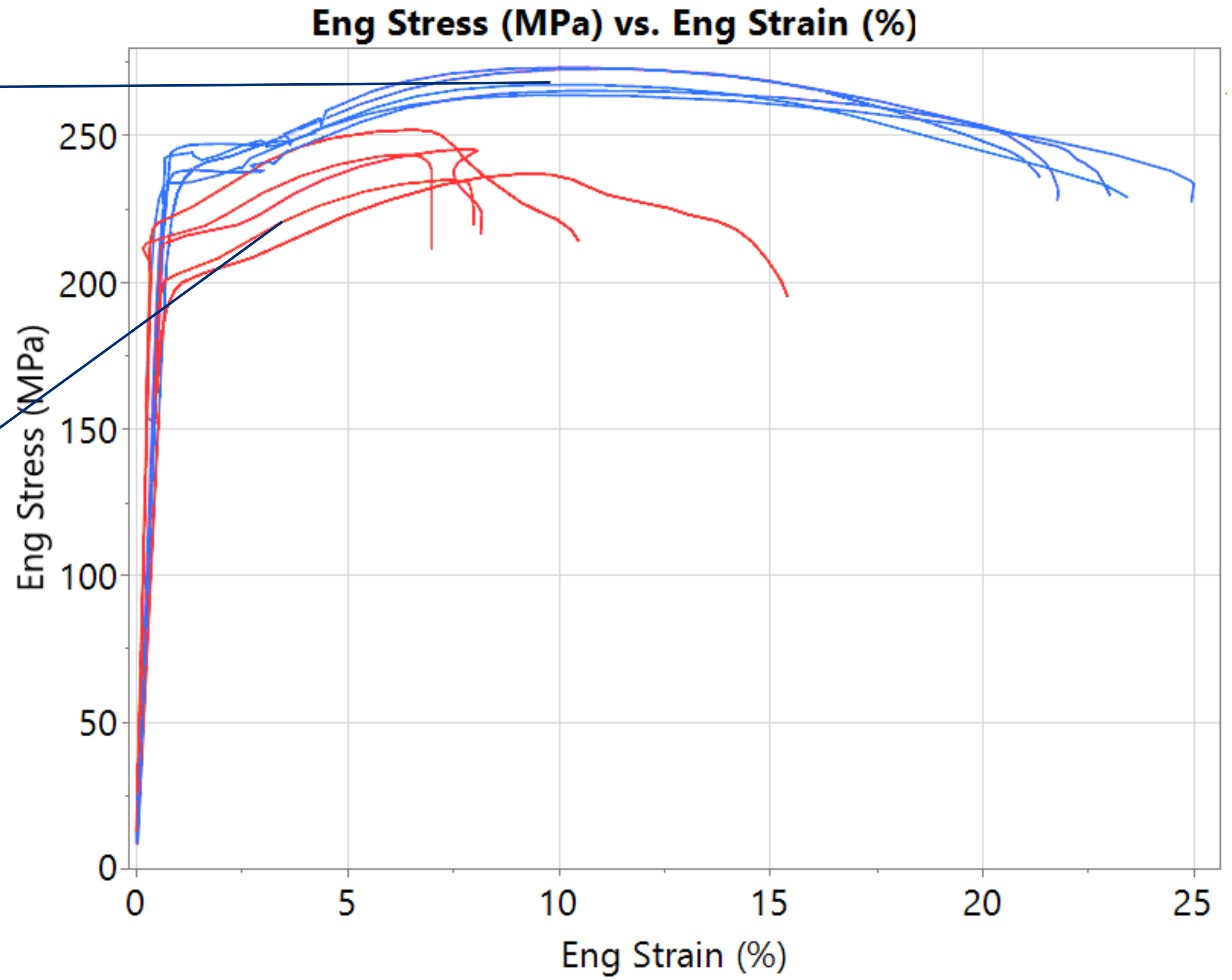
Laser-powder bed fusion (L-PBF) can produce low porosity hardware similar to wrought when the AM process is optimized.

Low Porosity

High Porosity

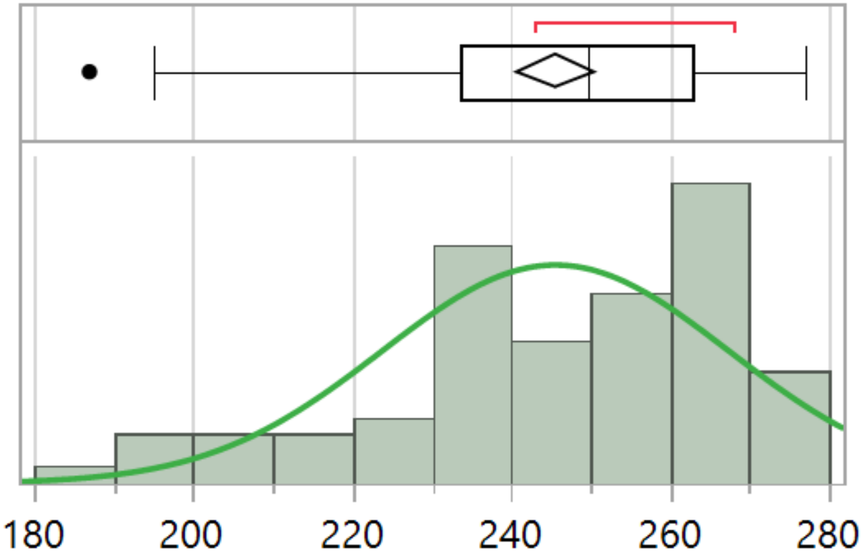


Fracture Surfaces



A design of experiment (DOE) was used to determine optimized build parameters for the laser-powder bed fusion (L-PBF) process.

YS (MPa)



Summary Statistics

Mean	245.56579
Std Dev	21.791947
Std Err Mean	2.4997077
Upper 95% Mean	250.54546
Lower 95% Mean	240.58612
N	76
Skewness	-0.796377
Minimum	187
Maximum	277
Range	90

Goodness-of-Fit Test

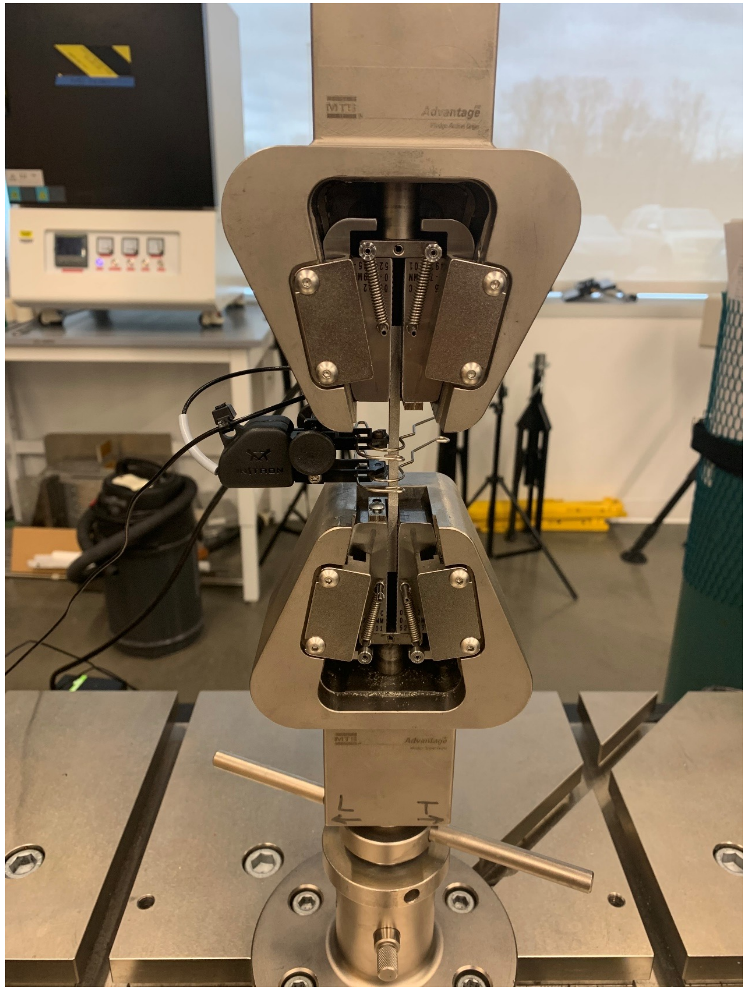
	W	Prob<W
Shapiro-Wilk	0.9349365	0.0007*

	A2	Prob > A2
Anderson-Darling	1.4406433	0.0010*

- ASTM E8 tensile test coupons, N = 76
- Includes all of the laser parameter sets from the DOE #2 parameter optimization study
- Data is skewed to lower YS values due to high porosity material that also had low strength (some higher porosity material had high strength)
- Goodness-of-Fit Test shows that the data is not normally distributed, although visually the shape isn't too bad

A design of experiment (DOE) was used to determine optimized build parameters for the laser-powder bed fusion (L-PBF) process.

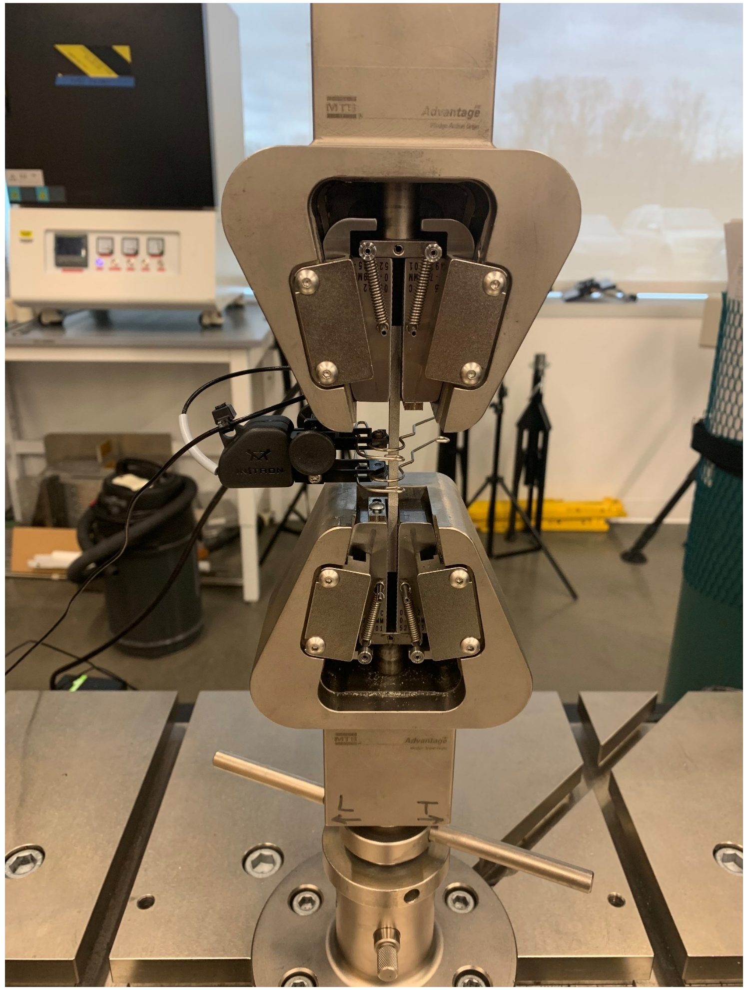
Property	DOE All Results	DOE Low Porosity
Number of Samples	76	45
UTS (MPa)	274 (mean) 244 (T99)	277 (mean)
YS (MPa)	246 (mean) 203 (T99)	255 (mean)
Elongation (%)	7.6 (mean) 4.7 (min)	–



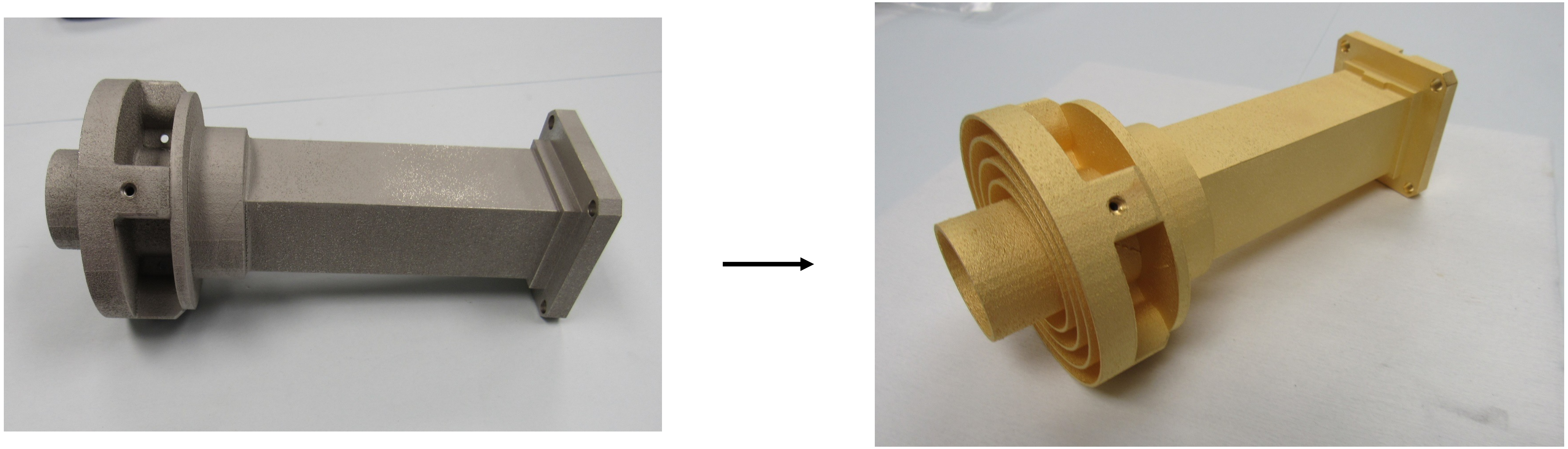
Witness tensile coupons build alongside flight antennas exhibited excellent mechanical properties.

Property	**DOE All Results**	**DOE Low Porosity**	**Witness Coupons**	**Elementum 3D Datasheet**	**Wrought 6061-T6**
Number of Samples	76	45	6	–	–
UTS (MPa)	274 (mean) 244 (T99)	277 (mean)	317 (mean)	331	310
YS (MPa)	246 (mean) 203 (T99)	255 (mean)	291 (mean)	297	276
Elongation (%)	7.6 (mean) 4.7 (min)	–	8.9	11-14	12-17

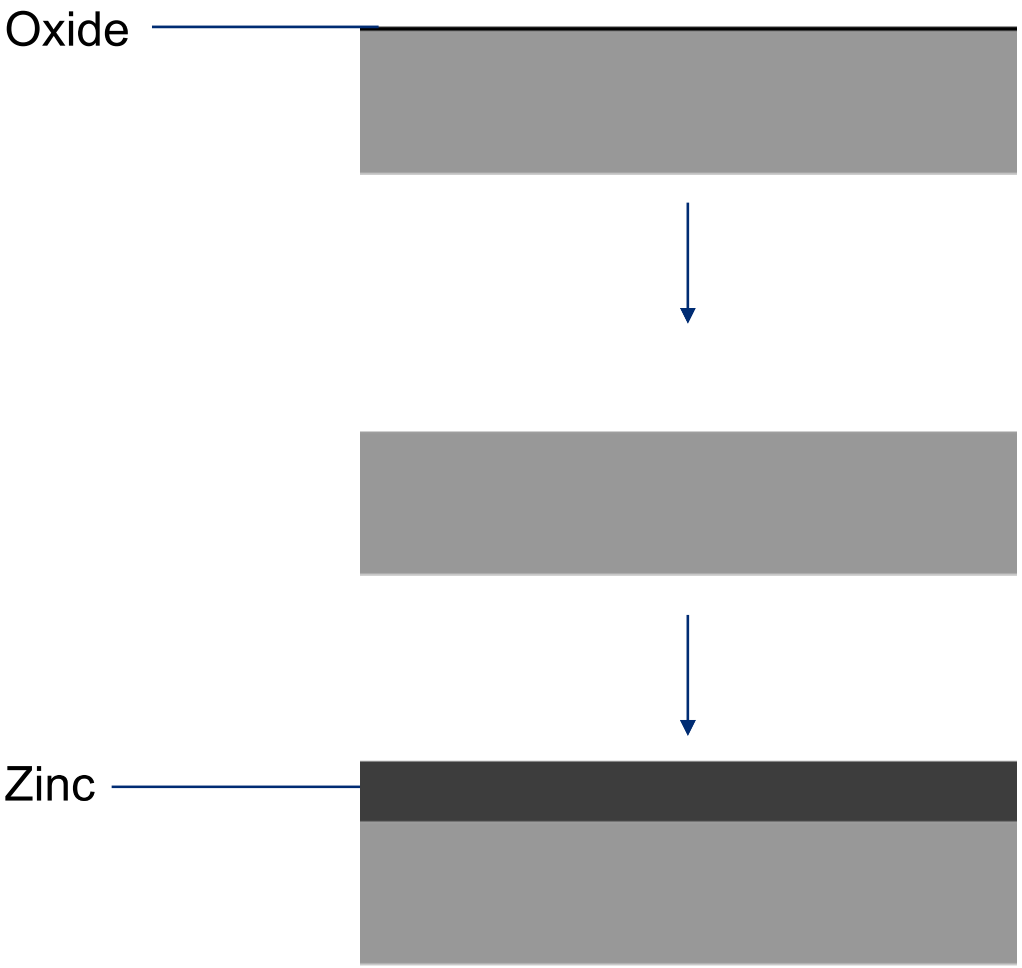
CONCLUSION: Mechanical properties were satisfactory for our spaceflight application.



Plating was used to address contamination concerns—corrosion protection, particulate encapsulation, and improved cleaning.



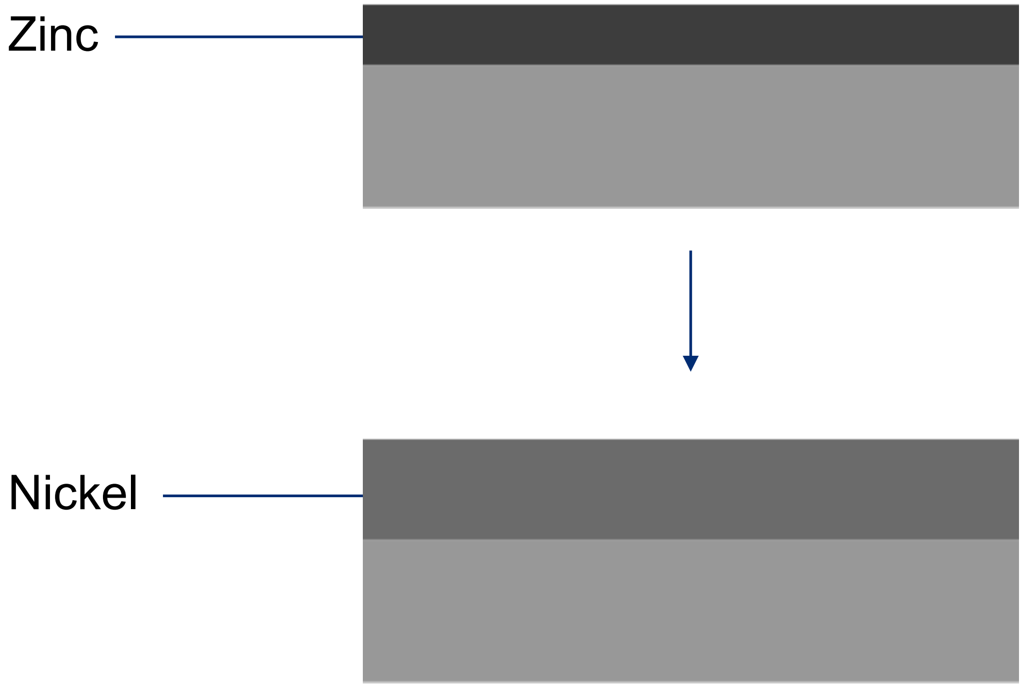
A modified zincate process was utilized to achieve an electroless nickel seed layer, followed by electrodeposited gold.



Step 1: Zincate Layer
A double zincate process with an enhanced etching step was used to remove the native oxide layer and other contaminants on the aluminum to allow for proper adhesion of the subsequent platings.

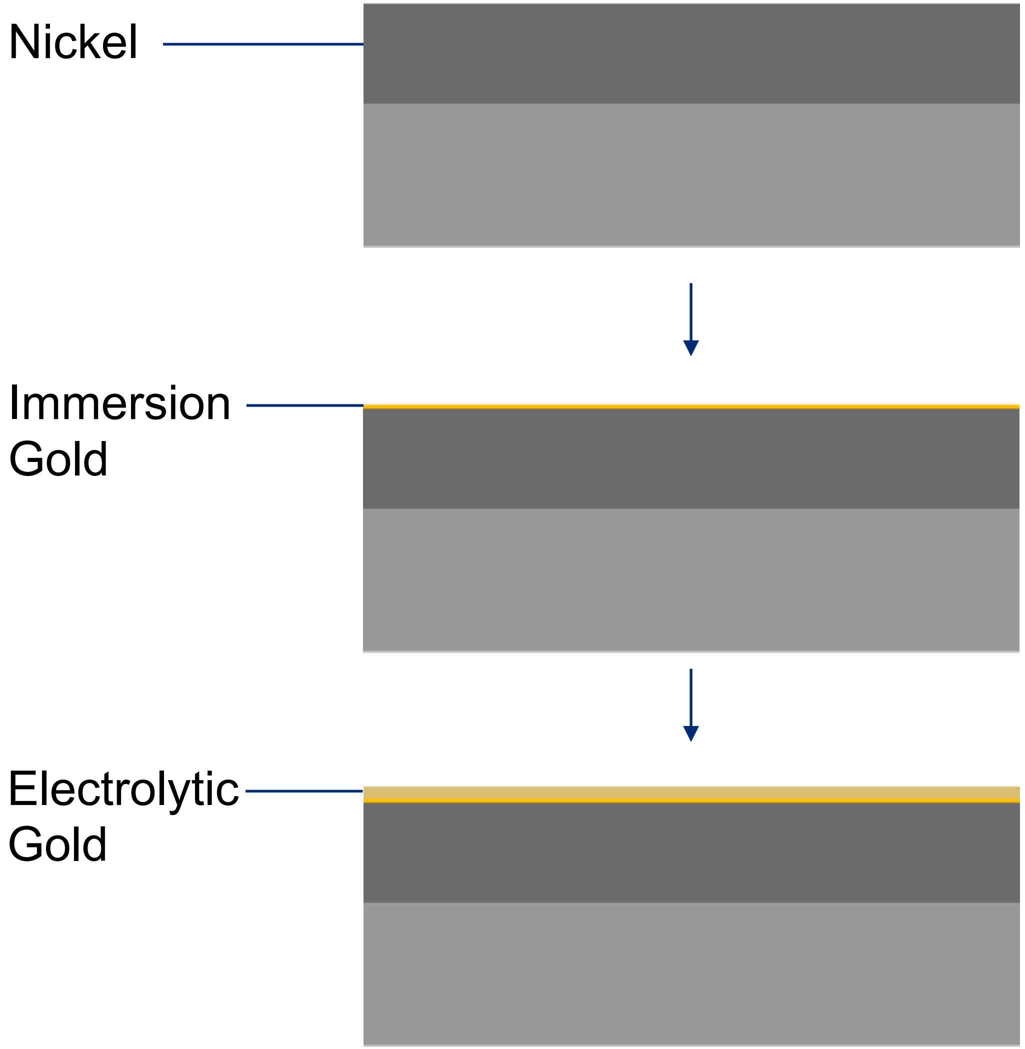
A modified zincate process was utilized to achieve an electroless nickel seed layer, followed by electrodeposited gold.

Step 2: Nickel Plate
Hardware receives 250 microinches of 6-8% phosphorus electroless nickel.

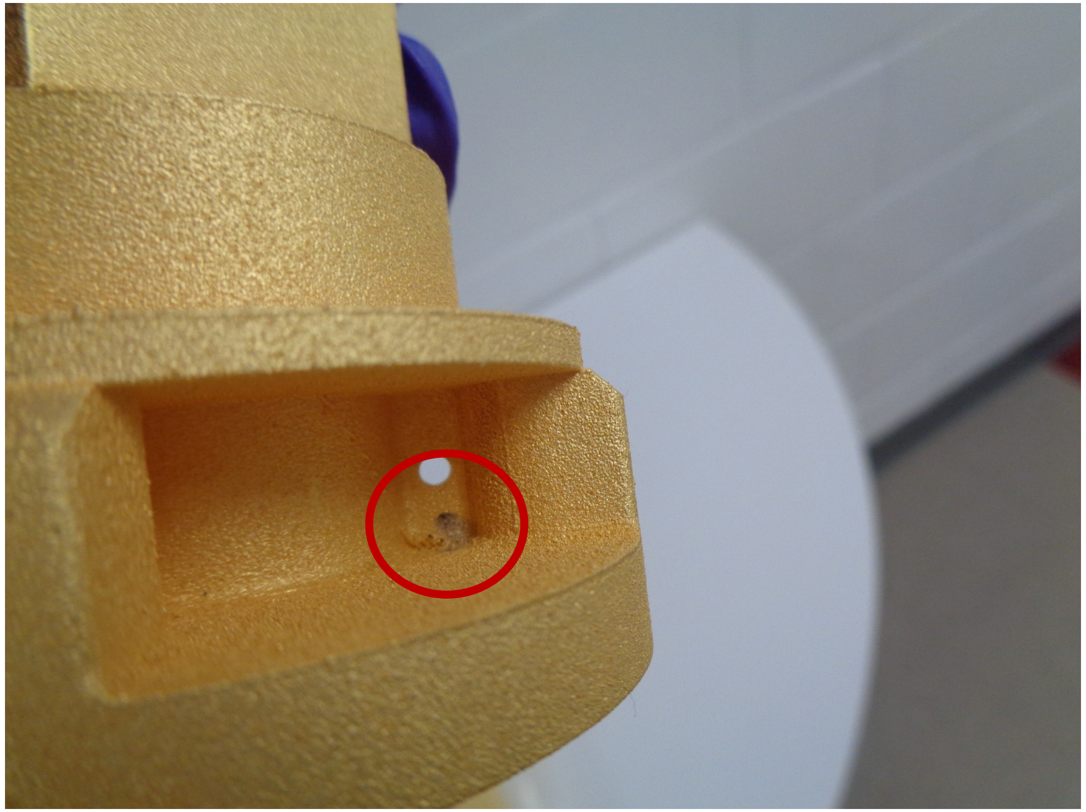


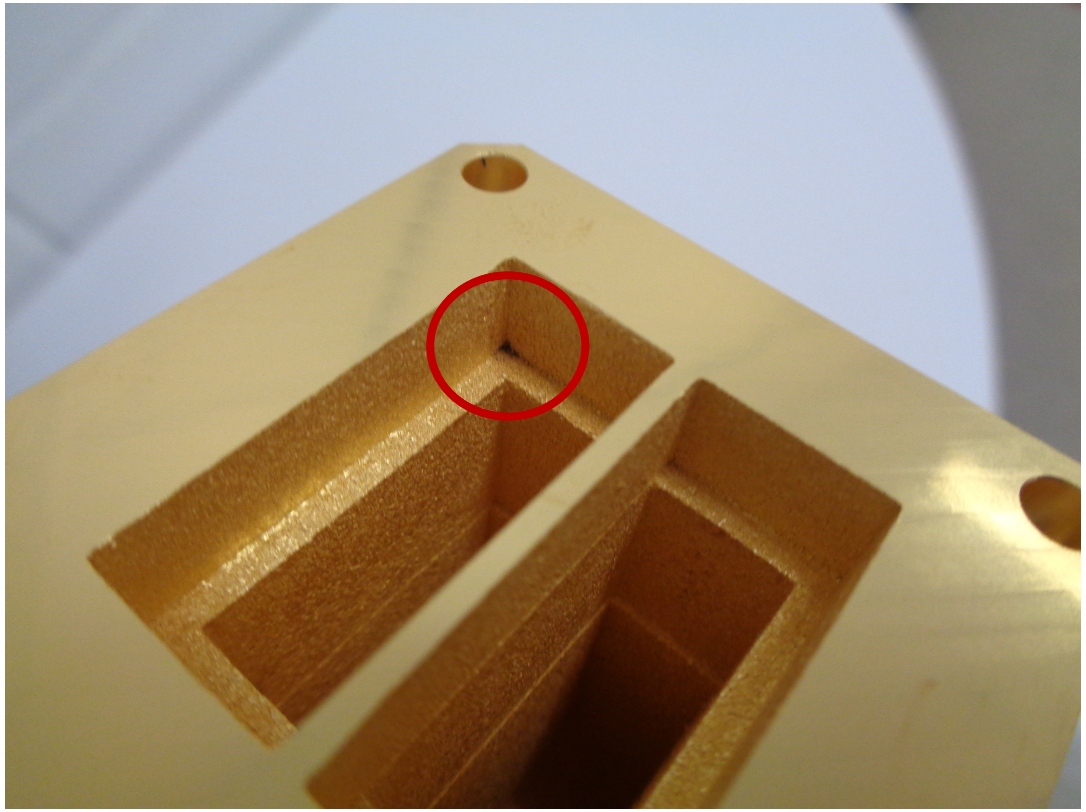
A modified zincate process was utilized to achieve an electroless nickel seed layer, followed by electrodeposited gold.

Step 3: Gold Plate
Hardware receives 2-3 microinches of immersion gold, followed by 20-40 microinches of electrolytic gold.

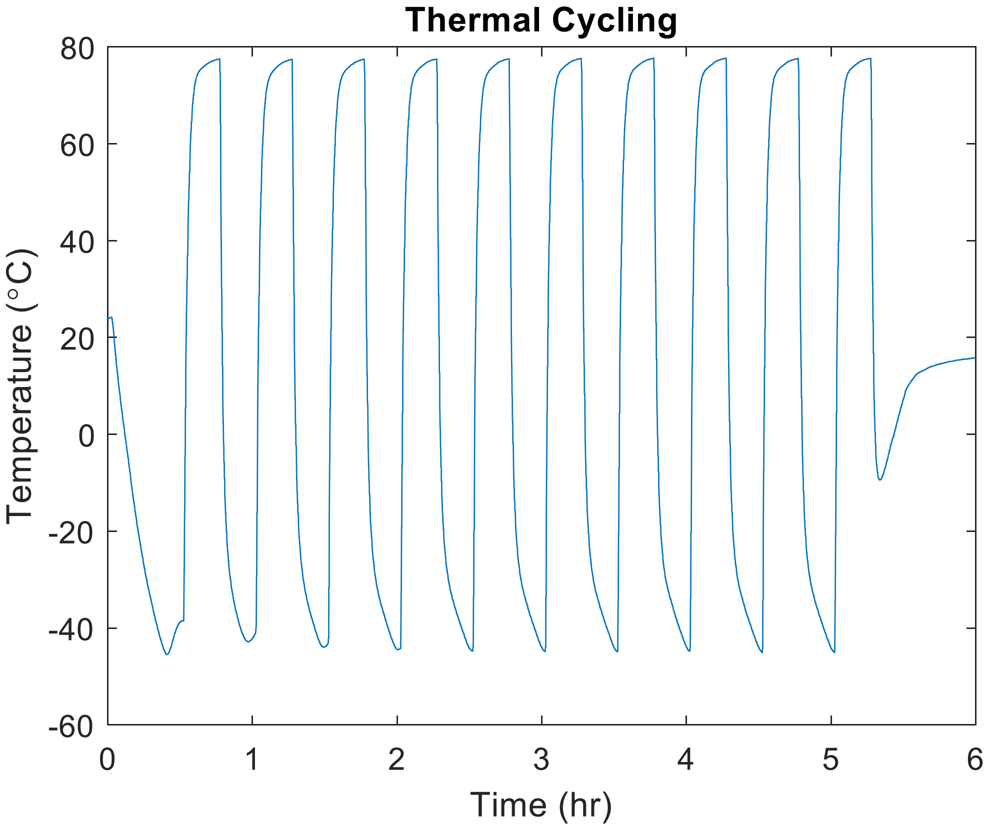


Coverage of the plating over the complex geometry was excellent, with few areas of thin or missing gold.



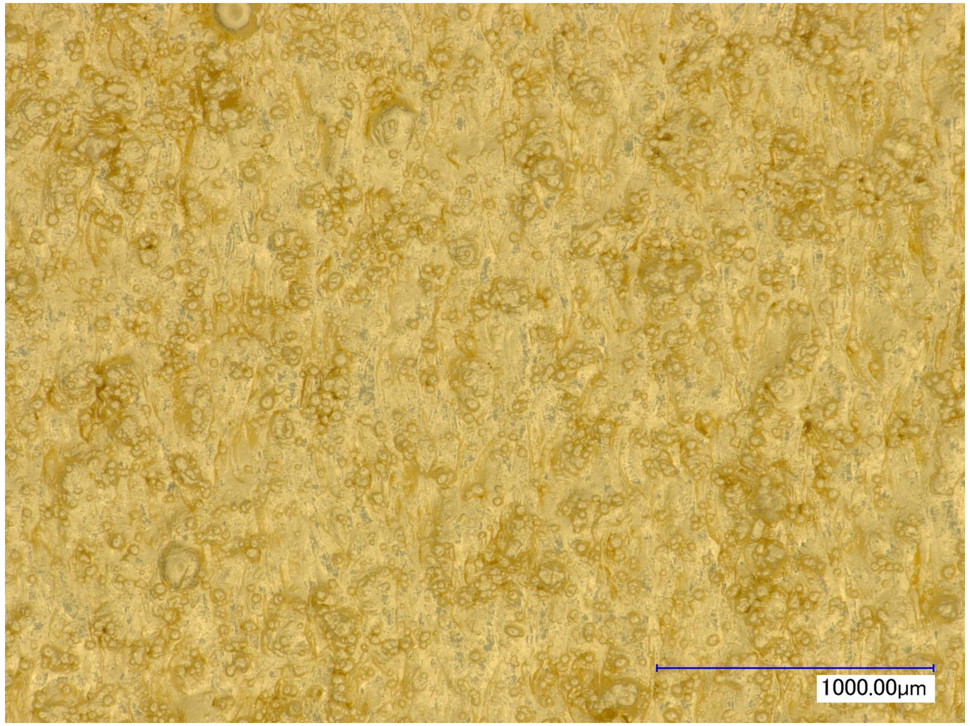


Both a plated prototype and plated witness coupons were subject to thermal cycling, both in air and in high vacuum.

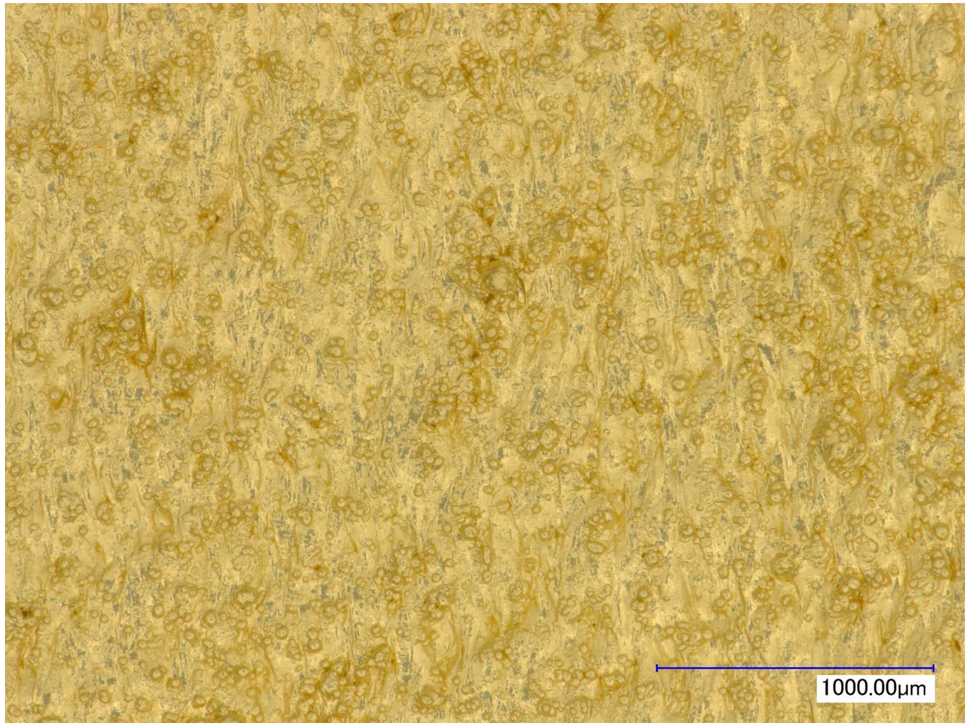


Thermal cycling was completed in a two-chamber system, in which samples on an elevator moved between a hot and cold chamber rapidly with 15 minutes dwell at temperature. Temperature change is near 36°C/min at maximum rate.

The plating was fully adherent and unaffected by thermal cycling, as determined by visual inspection and an ASTM D3359 tape pull.

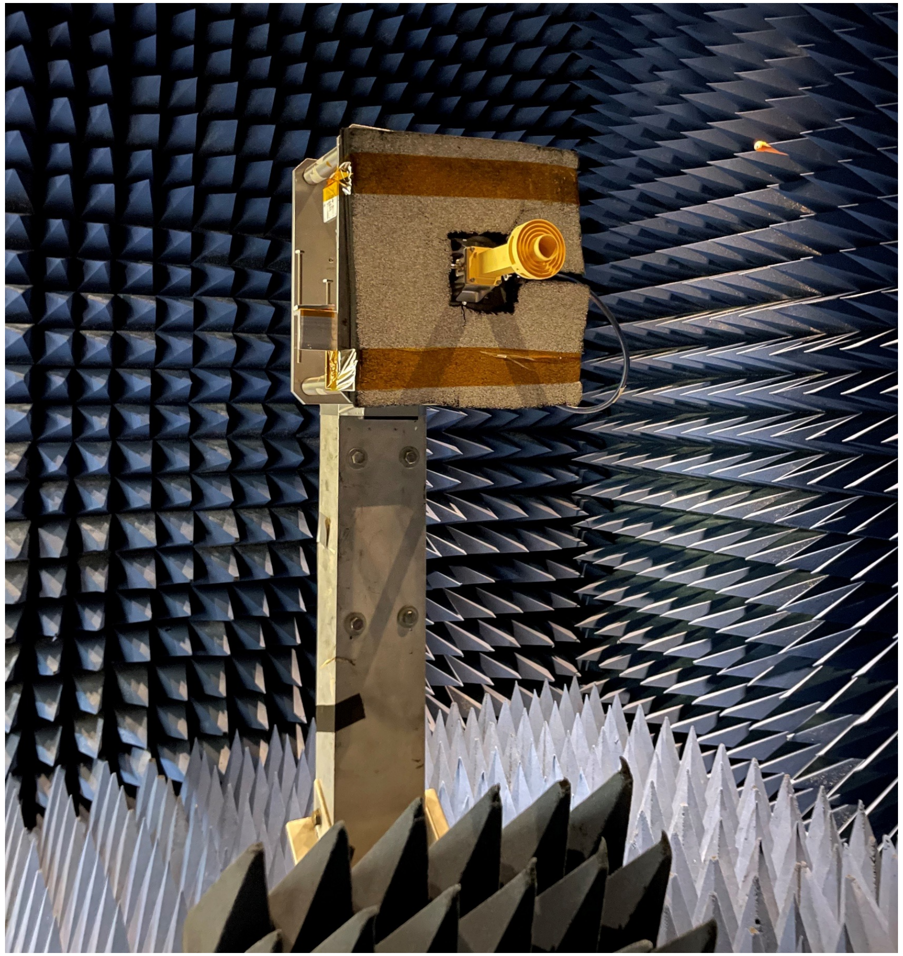


Before Thermal Cycling



After Thermal Cycling

The finished antenna passed vibration testing and met all RF requirements.



CONCLUSION: AM is a promising route for future RF hardware.

APL

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