HPS High Performance Space Structure Systems GmbH GERMANY

Qualification of Additive Manufacturing for Antenna applications (3DPAN2)

Final Presentation

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Munich |September 05th 2024

Agenda:

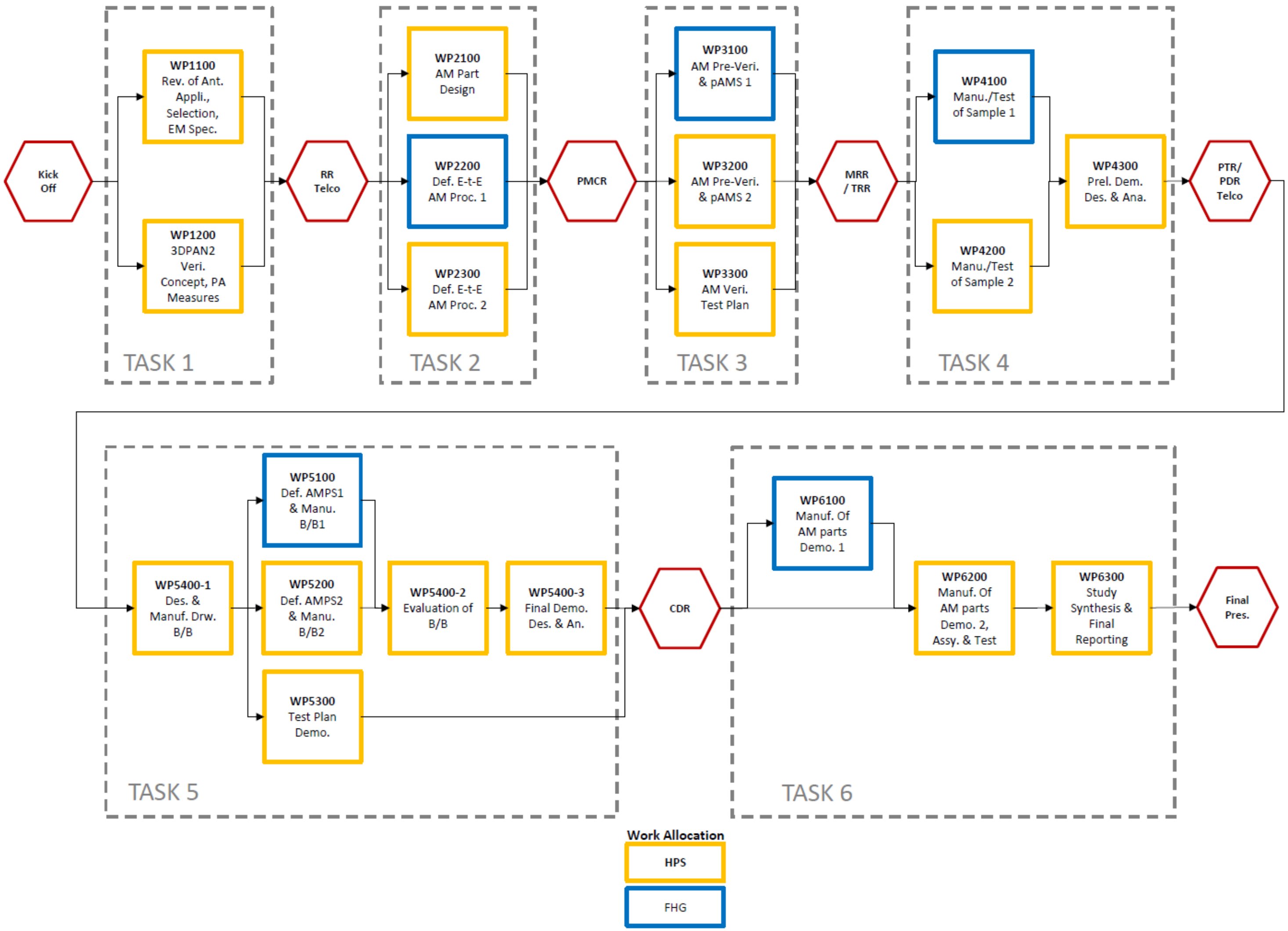
1. Project Goals
2. Requirement Definition of selected RF Applications
3. AM Process Definition
4. AM Process Pre-verification
5. Design Maturation
6. Verification of AM Process
7. Demonstrator Manufacturing and Testing
8. Conclusion and Next Steps

1. Project Goals

Objectives

- Select RF components suitable for Additive Manufacturing (AM)
- Application of the AM process according to ECSS-Q-ST-70-80C on selected parts
- Prepare AM process specification (AMPS) for the selected components
- Generate Lessons Learnt for the manufacturing of AM parts
- Raise the manufacturing technology from level TRL 4 to TRL 5 or higher.

Study Plan Flow Chart



Task 1: Requirement definition of selected RF applications

Task 2: AM Process Definition

Task 3: AM Pre-Verification

Task 4: Design Maturation

Task 5: Verification of AM Process

Task 6: Demonstrators manufacturing and testing

Schedule

Project start:

03/2020

Project end (plan):

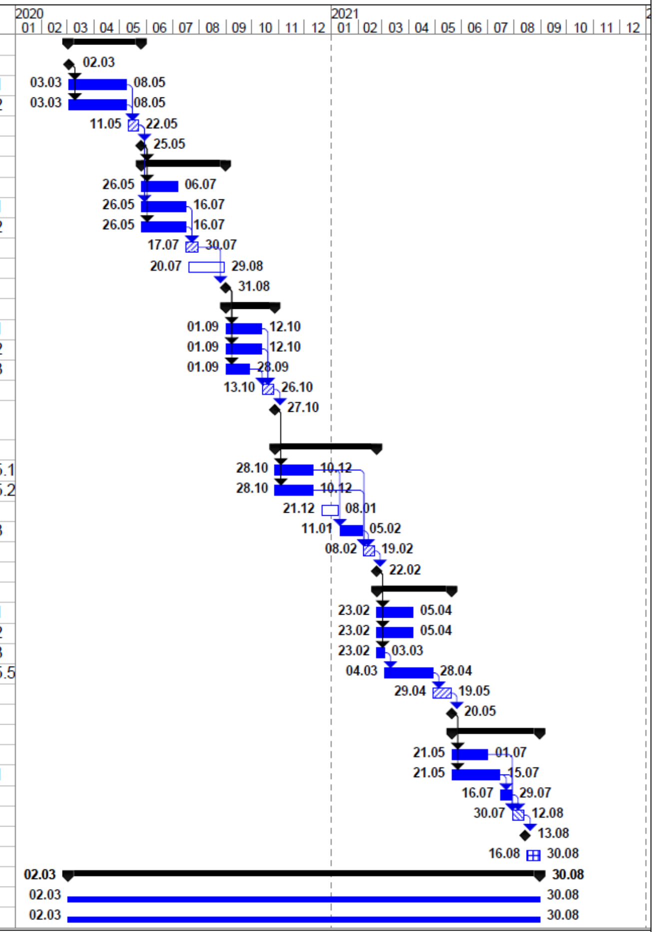
30.08.2021 (1,5 years)

Project end (as-is):

09/2024 (4,5 years)

3D Printed Antenna Structures Follow-on (3DPAN2)

Nr.	WP-N°	Task Name	Dauer	Company	Doc.
1	**1000**	**Requirement Definition of Selected RF Application**	**61 Tage**	**-**	**-**
2	-	Kick-Off (ESTEC, Noordwijk)	1 Tag	-	-
3	1100	Revisit of Antenna Applications, Selection & EM Specification	49 Tage	HPS	TN1.1
4	1200	3DPAN2 Verification Concept & Def. Of Minimum PA Measure	49 Tage	HPS	TN1.2
5	-	*Document Review by ESA*	10 Tage	-	-
6	-	Requirement Review (Telecon)	1 Tag	-	-
7	**2000**	**AM Process Definition**	**70 Tage**	**-**	**-**
8	2100	AM Part Design	30 Tage	HPS	-
9	2200	Definition of End-to-End AM Process 1	38 Tage	FHG IWS	TN2.1
10	2300	Definition of End-to-End AM Process 2	38 Tage	HPS (ext.)	TN2.2
11	-	*Document Review by ESA*	10 Tage	-	-
12	-	German Summer Holiday Period	30 Tage		
13	-	Preliminary Manufacturing Concept Review (HPS, Munich)	1 Tag	-	-
14	**3000**	**AM Process Pre-Verification**	**41 Tage**	**-**	**-**
15	3100	AM Pre-Verification & Prel. AM Procedure Specification 1	30 Tage	FHG IWS	TN3.1
16	3200	AM Pre-Verification & Prel. AM Procedure Specification 2	30 Tage	HPS (ext.)	TN3.2
17	3300	AM Verification Test Plan	20 Tage	HPS	TN3.3
18	-	*Document Review by ESA*	10 Tage	-	-
19	-	Sample Manufacturing Readiness Review &Test Readiness Review (HPS, Munich)	1 Tag	-	-
20	**4000**	**Design Maturation**	**84 Tage**	**-**	**-**
21	4100	Manufacturing and Testing of Sample 1	32 Tage	FHG IWS	TN4.1/5.1
22	4200	Manufacturing and Testing of Sample 2	32 Tage	HPS (ext.)	TN4.2/5.2
23	-	Winter Holiday	15 Tage	-	-
24	4300	Preliminary Demonstrators Design & Analysis	20 Tage	HPS	TN4.3
25	-	*Document Review by ESA*	10 Tage	-	-
26	-	Post-Test Review & Prelimin. Design Review (Telecon)	1 Tag	-	-
27	**5000**	**AM Process Verification**	**63 Tage**	**-**	**-**
28	5100	Definition of AM Procedure Specification 1 & Manuf. B/B1	30 Tage	FHG IWS	SP1.1
29	5200	Definition of AM Procedure Specification 2 & Manuf. B/B2	30 Tage	HPS (ext.)	SP1.2
30	5300	Test Plan for Demonstrators	7 Tage	HPS	TN5.3
31	5400	Final Demonstrator Design and Analysis & B/B Verification	40 Tage	HPS	TN5.4/5.5
32	-	*Document Review by ESA*	15 Tage	-	-
33	-	Critical Design Review (HPS, Munich)	1 Tag	-	-
34	**6000**	**Demonstrator Manufacturing and Testing**	**72 Tage**	**-**	**-**
35	6100	Manufacturing of AM Parts of Demonstrator 1	30 Tage	FHG IWS	-
36	6200	Manufacturing of AM Parts of Demonstrator 2, Assembly and Test	40 Tage	HPS (ext.)	TN6.1
37	6300	Study Synthesis & Final Reporting	10 Tage	HPS	FR
38	-	*Document Review by ESA*	10 Tage	-	-
39	-	Final Review (ESTEC, Noordwijk)	1 Tag	-	-
40	-	Project Margin	11 Tage	-	-
41	**7000**	**Project Management & Travel Cost**	**391 Tage**	**-**	**-**
42	7100	Project Management & Travel Cost	391 Tage	HPS	-
43	7200	Local Project Management	391 Tage	FHG IWS	-



HPS GmbH, Munich, Germany

Issue 1, Print Date: Mit 04.12.19

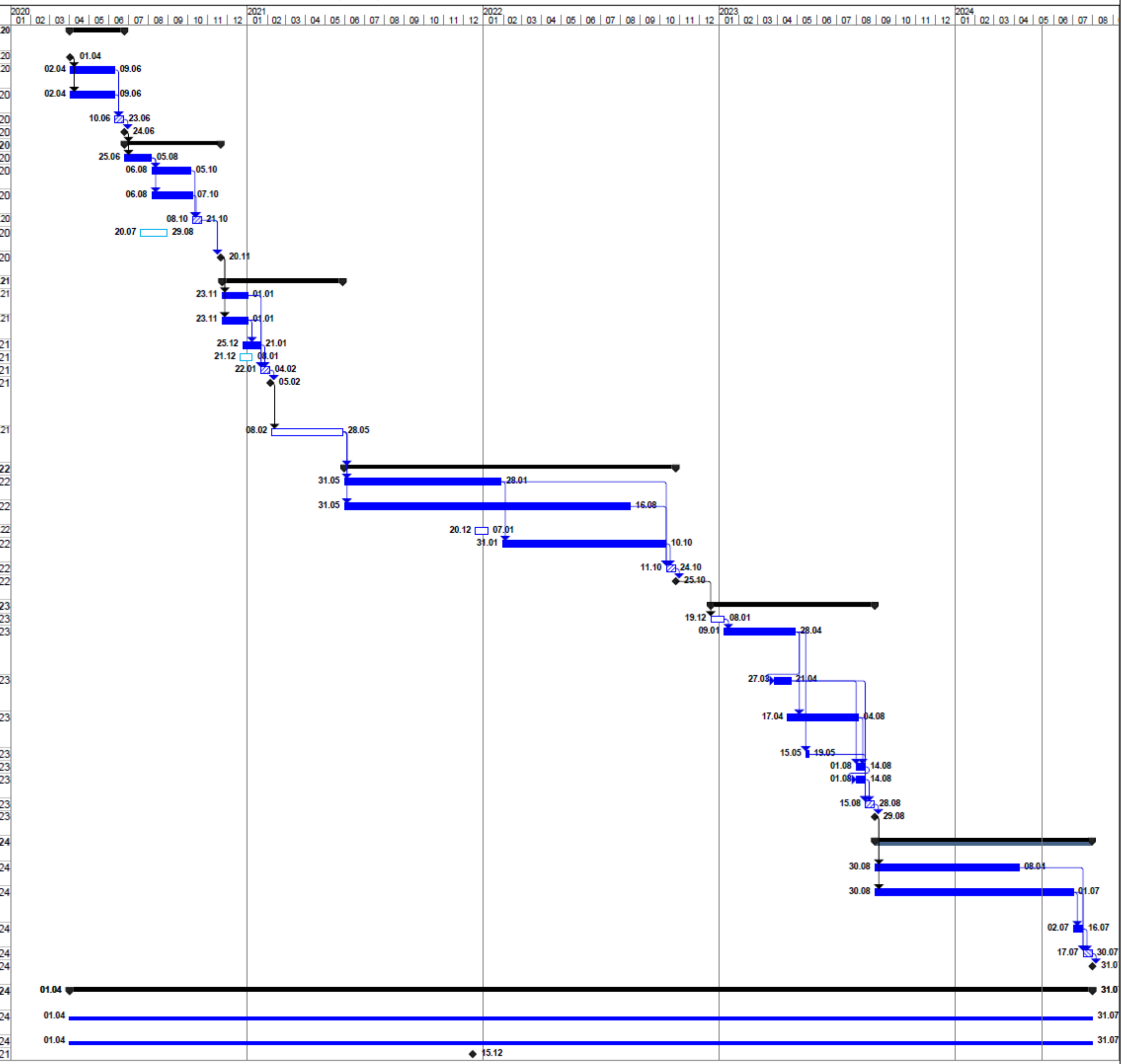
Extended due to:

- Covid 19
- Staff availability (HERA)
- Access/ availability to facilities (post-processing, test)
- Longer delievery time
- Extra purchase of powder (FHG IWS)

Schedule

3D Printed Antenna Structures Follow-on (3DPAN2)

Nr.	WP-Nº	Task Name	Dauer	Company	Doc.	Anfang	Ende
1	1000	**Requirement Definition of Selected RF Application**	**61 Tage**	-	-	**Mit 01.04.20**	**Mit 24.06.20**
2	-	Kick-Off (ESTEC, Noordwijk)	1 Tag	-	-	Mit 01.04.20	Mit 01.04.20
3	1100	Revisit of Antenna Applications, Selection & EM	49 Tage	HPS	TN1.1	Don 02.04.20	Die 09.06.20
4	1200	3DPAN2 Verification Concept & Def. Of Minimum PA	49 Tage	HPS	TN1.2/ 7 iss.1	Don 02.04.20	Die 09.06.20
5	-	*Document Review by ESA*	10 Tage	-	-	Mit 10.06.20	Die 23.06.20
6	-	Requirement Review (Telecon)	1 Tag	-	-	Mit 24.06.20	Mit 24.06.20
7	2000	**AM Process Definition**	**107 Tage**	-	-	**Don 25.06.20**	**Fre 20.11.20**
8	2100	AM Part Design	30 Tage	HPS	-	Don 25.06.20	Mit 05.08.20
9	2200	Definition of End-to-End AM Process 1	43 Tage	FHG IWS	TN2.1	Don 06.08.20	Mon 05.10.20
10	2300	Definition of End-to-End AM Process 2	45 Tage	HPS (ext.)	TN2.2/ 7 iss.2	Don 06.08.20	Mit 07.10.20
11	-	*Document Review by ESA*	10 Tage	-	-	Don 08.10.20	Mit 21.10.20
12	-	German Summer Holiday Period	30 Tage			Mon 20.07.20	Sam 29.08.20
13	-	Preliminary Manufacturing Concept Review (HPS,	1 Tag	-	-	Fre 20.11.20	Fre 20.11.20
14	3000	**AM Process Pre-Verification**	**135 Tage**	-	-	**Mon 23.11.20**	**Fre 28.05.21**
15	3100	AM Pre-Verification & Prel. AM Procedure Specification 1	30 Tage	FHG IWS	TN3.1	Mon 23.11.20	Fre 01.01.21
16	3200	AM Pre-Verification & Prel. AM Procedure Specification 2	30 Tage	HPS (ext.)	TN3.2/ 7 iss.3	Mon 23.11.20	Fre 01.01.21
17	3300	AM Verification Test Plan	20 Tage	HPS	TN3.3	Fre 25.12.20	Don 21.01.21
18	-	Winter Holiday	15 Tage	-	-	Mon 21.12.20	Fre 08.01.21
19	-	*Document Review by ESA*	10 Tage	-	-	Fre 22.01.21	Don 04.02.21
20	-	Sample Manufacturing Readiness Review &Test Readiness Review (HPS, Munich)	1 Tag	-	-	Fre 05.02.21	Fre 05.02.21
21	-	Short project break (Facilities access limitations/ Corona quarantine)	80 Tage			Mon 08.02.21	Fre 28.05.21
22	4000	**Design Maturation**	**367 Tage**	-	-	**Mon 31.05.21**	**Die 25.10.22**
23	4100	Manufacturing and Testing of Sample 1	175 Tage	FHG IWS	TN4.1/ 5.1	Mon 31.05.21	Fre 28.01.22
24	4200	Manufacturing and Testing of Sample 2	317 Tage	HPS (ext.)	TN4.2/ 5.2/ 7 iss.4	Mon 31.05.21	Die 16.08.22
25		Winter Holiday	15 Tage			Mon 20.12.21	Fre 07.01.22
26	4300	Preliminary Demonstrators Design & Analysis	181 Tage	HPS	TN4.3	Mon 31.01.22	Mon 10.10.22
27	-	*Document Review by ESA*	10 Tage	-	-	Die 11.10.22	Mon 24.10.22
28	-	Post-Test Review & Prelimin. Design Review (Telecon)	1 Tag	-	-	Die 25.10.22	Die 25.10.22
29	5000	**AM Process Verification**	**182 Tage**	-	-	**Mon 19.12.22**	**Die 29.08.23**
30		Winter Holiday	15 Tage			Mon 19.12.22	Son 08.01.23
31	5400-1	Breadboard Design and Manufacturing Drawing (B/B1: Feed Tower, BB2: Reflector Antenna)	80 Tage	HPS	TN5.4/ 5.5	Mon 09.01.23	Fre 28.04.23
32	5100	Definition of AM Procedure Specification 1 & Manuf. B/B1 (Feed Tower)	20 Tage	FHG IWS	SP1.1	Mon 27.03.23	Fre 21.04.23
33	5200	Definition of AM Procedure Specification 2 & Manuf. B/B2 (Reflector Antenna)	80 Tage	HPS (ext.)	SP1.2/ TN 7 iss.5	Mon 17.04.23	Fre 04.08.23
34	5300	Test Plan for Demonstrators	5 Tage	HPS	TN5.3	Mon 15.05.23	Fre 19.05.23
35	5400-2	Evaluation of B/B	10 Tage	HPS	TN5.4/ 5.5	Die 01.08.23	Mon 14.08.23
36	5400-3	Final Demonstrators Design and Analysis	10 Tage	HPS	TN5.4/ 5.5	Die 01.08.23	Mon 14.08.23
37	-	*Document Review by ESA*	10 Tage	-	-	Die 15.08.23	Mon 28.08.23
38	-	Critical Design Review (HPS, Munich)	1 Tag	-	-	Die 29.08.23	Die 29.08.23
39	6000	**Demonstrator Manufacturing and Testing**	**240 Tage**	-	-	**Mit 30.08.23**	**Die 30.07.24**
40	6100	Manufacturing of AM Parts of Demonstrator 1 (Feed Tower)	159 Tage	FHG IWS	-	Mit 30.08.23	Mon 08.04.24
41	6200	Manufacturing of AM Parts of Demonstrator 2 (Reflector Antenna), Assembly and Test	219 Tage	HPS (ext.)	TN6.1	Mit 30.08.23	Mon 01.07.24
42	6300	Study Synthesis & Final Reporting	11 Tage	HPS	FR/ TN 7 iss.6	Die 02.07.24	Die 16.07.24
43	-	*Document Review by ESA*	10 Tage	-	-	Mit 17.07.24	Die 30.07.24
44	-	Final Review (ESTEC, Noordwijk)	1 Tag	-	-	Mit 31.07.24	Mit 31.07.24
45	7000	**Project Management & Travel Cost**	**1131 Tage**	-	-	**Mit 01.04.20**	**Mit 31.07.24**
46	7100	Project Management & Travel Cost	1131 Tage	HPS	-	Mit 01.04.20	Mit 31.07.24
47	7200	Local Project Management	1131 Ta...	FHG IWS	-	Mit 01.04.20	Mit 31.07.24
48	-	Contractual FP	1 Tag			Mit 15.12.21	Mit 15.12.21

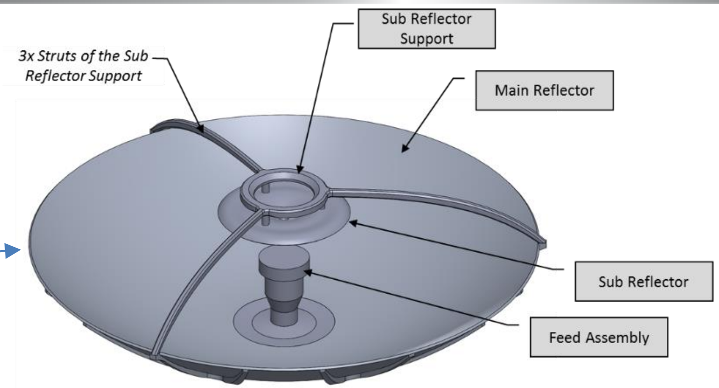


2. Requirement Definition of selected RF Applications (Task 1)

WP 1100: Selection of RF applications

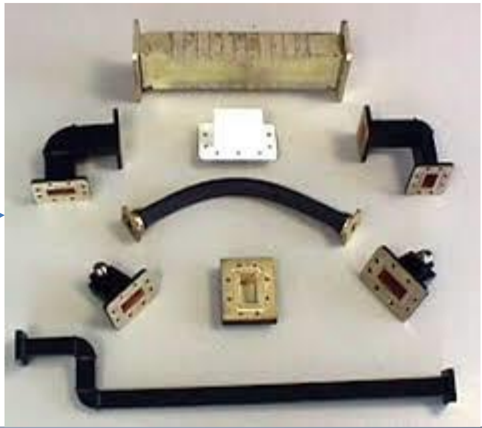
Reflective Elements (9 applications):

- Antenna Reflector Assembly
- Mesh-type reflective surface.



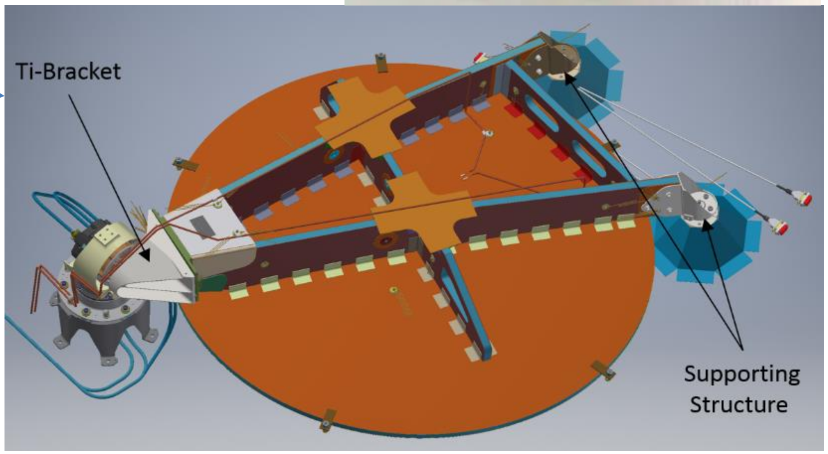
Feed Chain (12 applications):

- Feeds
- Horn antennas
- Waveguides
- Polarizer
- Rotary Joint.



Support Structures & Elements (20 applications):

- Reflectors support brackets and Interface elements
- Components for large deployable reflector systems
- Backing structures for Mesh-Reflectors.



WP 1100: Selection Criteria

1. Technical feasibility:

   Availability of AM machine and material on market

2. Post process effort:

   Complexity of post process

3. Technical product improvement compared to conventional technology:

   mass reduction; functional integration

4. Benefit for customer compared to conventional technology:

   faster delivery time; lower mass

5. Benefit for HPS compared to conventional technology:

   faster time to market; less AIT effort; innovative design

6. Economical/ strategic aspects for HPS:

   current portfolio; future development

WP 1100: Rating Range/ Weighting Factor

Rating values: 0 (not feasible) to 3 (fully feasible/common use)

Example: Technical feasibility:

0: not feasible (no suitable AM machine and/or no suitable material)

1: technology only as concept

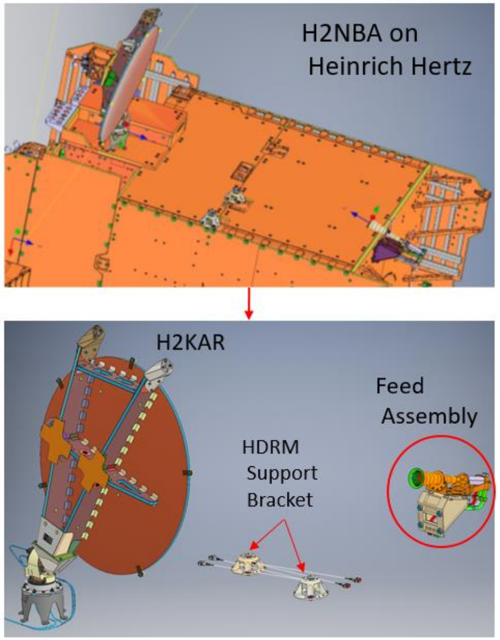
2: AM system available and qualified, no suitable material

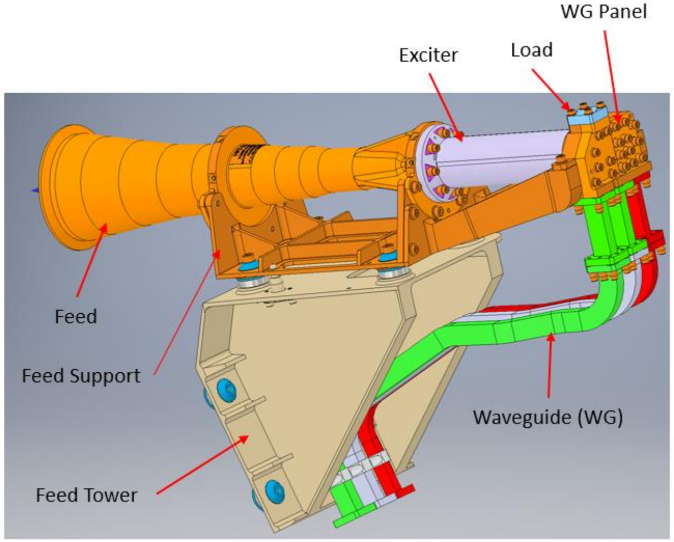
3: AM system and material commercially available.

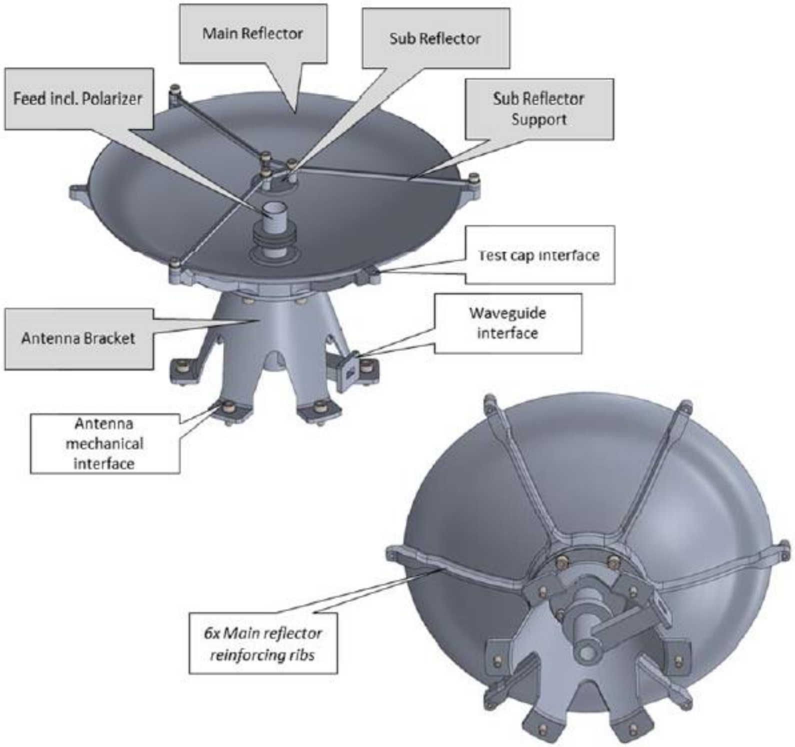
Weighting Factor:

Criteria for selection of 3DPAN2 application	Weighting Factor
Technical feasibility	6
Post Process Effort	1
Technical Product improvement	5
Benefit for customer	2
Benefit for HPS	4
Economic/ strategic aspects for HPS	3

WP 1100: Selected Applications







Application 1: Feed Tower

Application 2: X-Band Antenna

WP 1100: General Requirements

General Factors of Safety:

standard values acc. To ECSS-E-ST-32-10C + ECSS-E-ST-32C (KM = 1.2, FoSY = 1.1, FoSU = 1,25)

Project factor KP = 1.2 (low information on AM)

WP 1100: Requirements Feed Tower

QSL:

Load Case	X [g]	Y [g]	Z [g]
1	20	5	5
2	-20	5	5
3	14.1	14.1	5
4	14.1	-14.1	5
5	-14.1	14.1	5
6	-14.1	-14.1	5
7	5	20	5
8	5	-20	5
9	5	5	20
10	5	5	-20

Sine

Axis	Frequency [Hz]	Level
All axis	5 – 22.3 22.3 – 100	± 10 mm ± 20 g

Random

Axis	Frequency [Hz]	Load	Axis	Frequency [Hz]	Load
X/ Y	20 – 100	+6 dB/oct	Z	20 – 100	+16 dB/oct
	100 – 500	0.1 g^2/Hz		100 – 350	0.5 g^2/Hz
	500 – 2000	-6 dB/oct		350 – 2000	-6 dB/oct
	g_{RMS}	**9.0 g**		g_{RMS}	**16.9 g**

Temperature:

Maximum temperature: +140°C

Minimum temperature: -95°C

Eigenfrequency: 161.4 Hz (from H2NBA)
Surface Roughness: Ra 0.8µm at interfaces
Mass: < 0.84 kg (from H2NBA)

WP 1100: Requirement X-Band Antenna 1/2

Requirement	Values
Mass	< 0.67 Kg
Size	D < 300mm; H 150mm
Frequency Range	8025 – 8400 MHz (X-band)
Number of channels	2 (RHCP + LHCP)
Total Insertion Loss	0.5 dB
Total Return Loss	22 dB
RF Power	40 W
Minimum Boresight Antenna Gain	23 dBi
Roughness Rz	< 6.3µm (reflective surface)
Accuracy	< 80µm main reflector < 40µm sub-reflector

WP 1100: Requirement X-Band Antenna 2/2

<table>
<tr><th>Requirement</th><th>Antenna</th></tr>
<tr><td>Temperature</td><td>+150°C to -150°C</td></tr>
<tr><td>QSL</td><td>30g, all 3 axis</td></tr>
<tr><td>Sine</td><td>
<table>
<tr><th>Axis</th><th>Frequency [Hz]</th><th>Level [g]</th><th>Sweep Rate [oct/min]</th></tr>
<tr><td>All axis</td><td>5 – 20
20 – 125</td><td>Max shaker amplitude
30</td><td>2</td></tr>
</table>
</td></tr>
<tr><td>Random</td><td>
<table>
<tr><th>Axis</th><th>Frequency [Hz]</th><th>Qualification Level</th></tr>
<tr><td rowspan="6">All
(3 axis)</td><td>20 – 100</td><td>+12 dB/oct</td></tr>
<tr><td>100 – 300</td><td>1.5 g²/Hz</td></tr>
<tr><td>300 – 650</td><td>-15 dB/oct</td></tr>
<tr><td>650 – 850</td><td>0.03 g²/Hz</td></tr>
<tr><td>850 – 2000</td><td>-6 dB/oct</td></tr>
<tr><td>g_{RMS}</td><td>21.4</td></tr>
</table>
</td></tr>
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WP 1200: Verification Plan

Pre-Verification
→ Establishment of pAMPS

Powder Validation
Process Parameters Definition
Post Process Definition
NDI Definition
Establishment of material properties

Test Definition	Pre-Verification Test Matrix
Tensile	Min. 3 samples in x/y and z direction, in total 9
Density	Min. 3 samples
Metallography	Min. 3 samples
Customized tests	On request by customer

Classification of AM criticality level

Class 1.1: Critical and structural
Failure results in loss of S/C, major components, loss of life or loss of control
Class 1:2: Critical, but non-structural
Failure reduce efficiency of system
Class 2: Non-critical, but structural
Failure reduce efficiency of system, but no loss of S/C
Class 3: Non-critical, non-structural
Failure does not affect other parts

Verification on Sample Level
→ Verification of pAMPS
→ Establishment of AMPS

Test Definition	Class 1.1	Class 1.2	Class 2	Class 3
Visual inspection	On all produced specimens			
Metallography	3 vertical full height bars, each 6 microsections			1 vertical full height bar, 3 microsections
Tensile test	Min. 2 build jobs with min. 10 samples, total min. 20			Min. 3 samples*
Fatigue test**	Non-Fatigue critical H/W: 1 build job with 10 samples Fatigue critical H/W: 2 build jobs with 12 samples, to create 1 Wöhler curve with 24 data points (at least 4 load levels with 6 samples)			-
X-Ray CT	On fatigue samples			-
Powder testing	If virgin powder (CoC needed), no powder testing required			-
Customized tests	On request by customer			

Remark:* class 3 tensile test as alternative to FHB; ** not for class 1.2 parts

Verification on Prototypes

Test Definition	Class 1.1	Class 1.2	Class 2	Class 3
Dimensional Control	On all prototypes and witness samples			
Visual inspection	100% on all prototypes and witness samples, as far as possible due to part complexity			
Tensile test	Min. 3 valid samples			-
X-Ray CT	100% on all prototypes			-
Density testing	2 full height bars; from one, 3 single sections			
Metallography	On one FHB			-
Powder testing	If virgin powder (CoC needed), no powder testing required			-
Powder capture sample	Testing only in case of non-conformance			
Customized tests	On request by customer			

Hardware

Part	Test Definition	Class 1.1	Class 1.2	Class 2	Class 3
AM H/W	X-Ray CT	100%		-	
	Visual inspection	100% or as far as possible due to part complexity			
	Dimensional control	100%			Sampling acc. ISO 2859-1 sensitivity level II, AQL 0.65
	Functional test or proof test	If no CT possible		-	
Witness samples	Tensile test	Min. 3 samples*			
	Density	2 FHB, 1 FHB as spare		1 FHB	1 FHB
	Metallography	On 1 FHB		-	-
	Chemical composition	On 1 FHB		-	-
	Powder Capture Sample	1			-

Remark:* class 3 tensile test as alternative to FHB

3. AM Process Definition (Task 2)

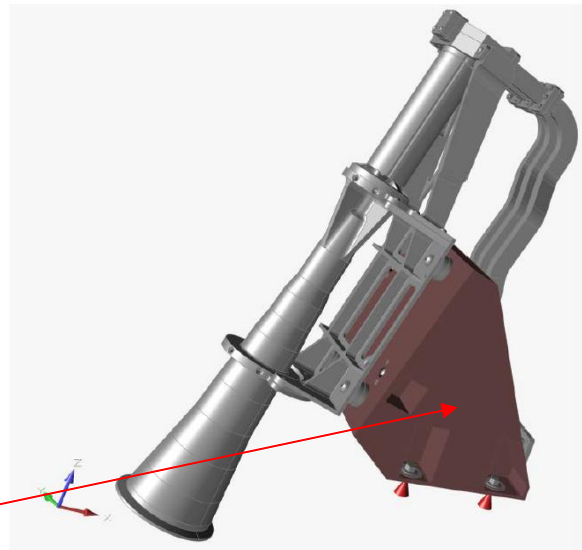
WP 2100: Material Selection Trade Off

Criteria	Feed Tower	Antenna
Function of the component	Support of Feed and waveguide assembly	Transfer signals between spacecraft and ground station
Constraints (Essential requirements)	First eigenfrequency > 161 Hz No plastic deformation Resist temperature: -95°C to + 140°C Low thermal deformation Low conductivity of thermal loads to S/C	First eigenfrequency > 100 Hz Stress below allowable strength Resist temperature: -145°C to +129°C Mass of main reflector: ≤ 470gr Mass of sub-reflector: ≤ 40gr
Objective	Minimize the mass of the feed tower Minimize thermal deformation Minimize thermal conductivity	Minimize the mass of the main and sub-reflector
Free variable	Choise of material	Choice of material
Target material property	Eigenfrequency: E ↑; m ↓ → E/ρ↑ Strength: MoS Yield ≥ 0; m ↓ → Rp0.2/ρ ↑ Thermal properties: λ ↓; minimize thermal displacement → λ/α ↓	Eigenfrequency: E ↑; m ↓ → E/ρ↑ Strength: MoS Yield ≥ 0; m ↓ → Rp0.2/ρ ↑
Selection	Ti6Al4V (other available material AlSi10Mg)	Scalmalloy (other available material AlSi10Mg and Ti6Al4V)

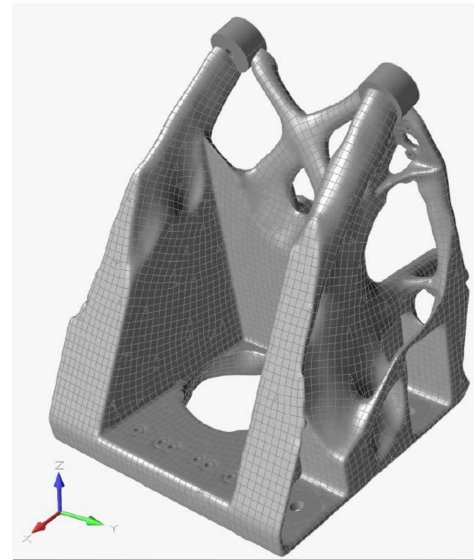
WP 2100: First Design

Feed Tower

Safety class 1



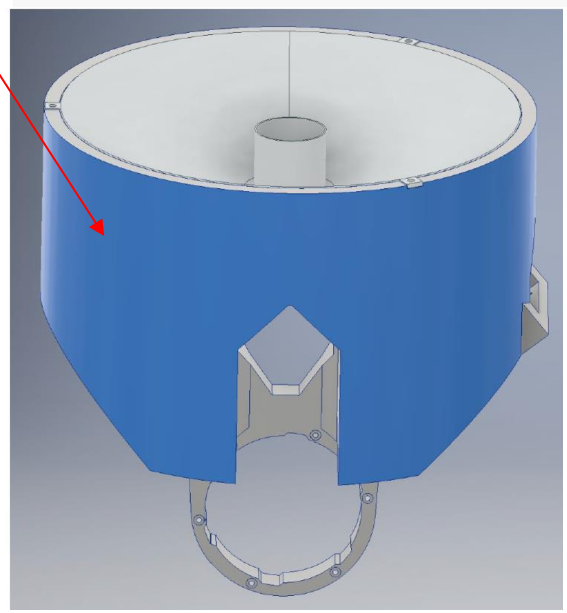
Topology Optimization



Design envelope

X-Band Antenna

Safety class 1



WP 2200: Definition End-to-End AM Process #1 (Feed Tower)

FHG IWS

WP 2300: Definition End-to-End AM Process #2 (Antenna)

Design:
1. Requirements
2. Structural optimization
3. Interpretation of results
4. Re-modelling in CAD
5. FE-Analysis
6. Final Design

↓

Data and Process Preparation:
1. Position and Orientation on Platform
2. Support Generation
3. Slicing

↓

Setup of Machine:
1. Preparation of Platform
2. Installation of Platform
3. Job Preparation
4. Unpacking
5. Sieving

↓

Post Processing:
1. Removal of Support Structure
2. Mechanical Rework
3. Surface Protection

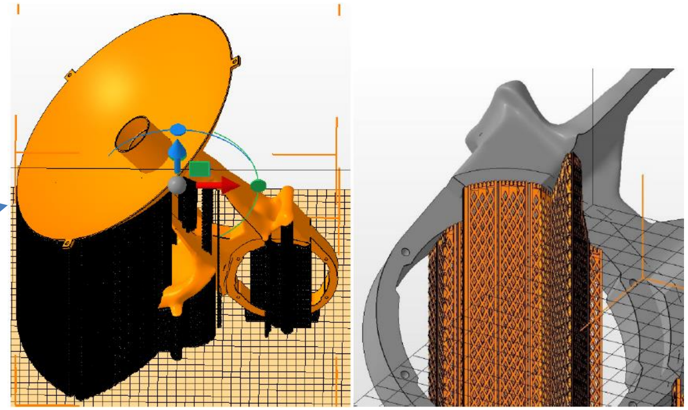
↓

Inspection and Testing:
1. Dimensional Control
2. Roughness Measurement
3. Porosity Check
4. Testing of Witness Samples

↓

Finished Part

AM supplier (Apworks)



Including definition of processing window:
- Type of AM machine (serial number)
- Process Parameters
- Software Tools

Organized in work instructions of AM supplier (Apworks)

Including Powder Removal, Heat Treatment, Support Removal (Apworks)
Mechanical rework + Surface protection (Surtec 650) by qualified supplier Pribil

Including:
- Visiual inspection (support failure, cracks)
- Dimensional control (Laser Radar)
- CT scan (porosity and cracks inside the part)

→ Establishment of Preliminary AM Process Specification (pAMPS) 2

4. AM Process Pre-verification (Task 3)

WP 3100: Pre-Verification 1 (Feed Tower)

FHG IWS

WP 3200: Pre-Verification 2 (X-Band Antenna) 1/2

Test Plan:

Test	Size	Orientation	Amount	Heat Treatment	Mechanical Rework
Density	20 x 20 x 20	n/a	1 2	AG AG + HIP	Milling
Tensile	DIN 50125 – B 6 x 30	0° 90° 0° 90°	7 7 7 7	AG AG AG + HIP AG + HIP	Turning
Porosity	CT on one density cube and one tensile sample for each heat treatment				

Post Process	Parameters	Reference
Ageing Heat Treatment (AG)	325°C / 4h	[RD4]
Hot-Isostatic Pressure (HIP)	325°C / 4h/ P > 1000bar	[RD4]
Tuning/Milling	n/a	n/a

Manufacturing and post-processing of samples acc. To pAMPS 2

Test Results:

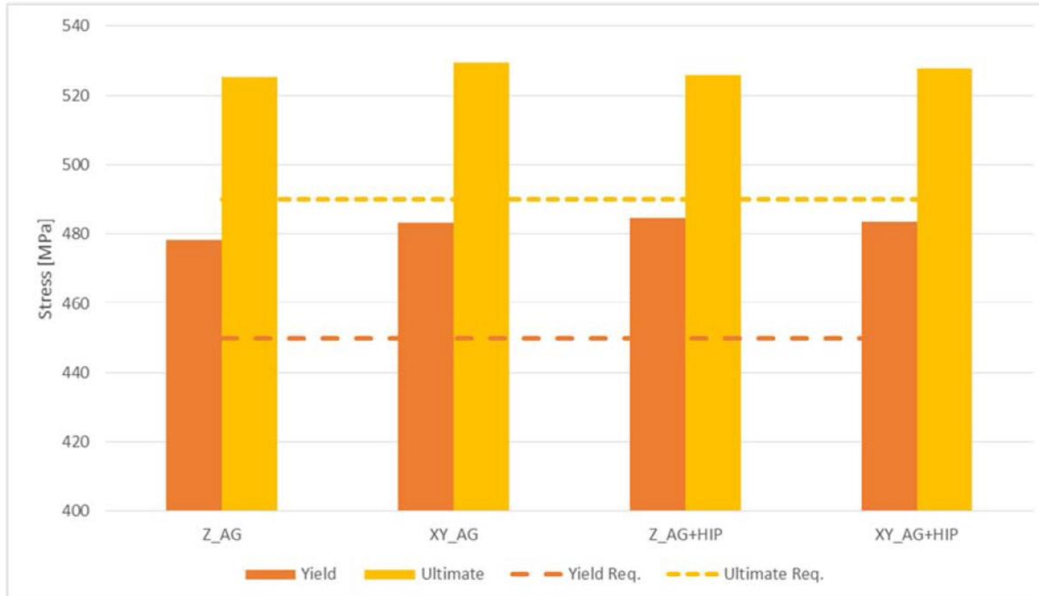
- **Powder Verification performed → inline with powder specifications**
- **NDI (visual inspection + dimensional control, CT scan)→no damages detected, HIP no influence**

Test	Sample ID	Orientation	Heat Treatment	Max Defect Volume [mm³]	Porosity [%]
Tensile	T1	90° = Z	Ageing	0.001	< 0.001
	T16	0° = XY		0.002	< 0.001
Density	D1	n/a		0.004	< 0.001
Tensile	T9	90° = Z	Ageing + HIP	0*	0*
	T25	0° = XY		0*	0*
Density	D2	n/a		0*	0*

Remark *: No pores/defects detected below voxel size of 20µm (= minimal detectable defect size ~60µm)

WP 3200: Pre-Verification 2 (X-Band Antenna) 2/2

- **Tensile Test Results (Mean values):**



- **Density Results**

Sample ID	Heat Treatment	Density [g/cm³]		Porosity [%]	Porosity [%]
		Method 1: Geometric	Method 2: Archimedes		Method: CT
D1	Aging	2,66	2,68	0[1]	< 0,001
D2	Aging + HIP	2,66	2,71	0[1]	0
D3		2,66	2,69	0[1]	0

→ **Pre-verification has shown process parameters are suitable, HIP can be excluded**

WP 3300: Test plan for verification Ti6Al4V

Test	Orien-tation	Geometry/ Standard	Heat Treatment	Post Process	Amount of Samples
Tensile	90°	DIN 50125 [RD6] See Figure 4	Annealing (AN)	As Build (AB)	7
				Sand-Blasted (SB)	7 + 7
				Shot Peening (SP)	7 + 7
Fatigue	90°	DIN 50113 [RD22] See Figure 8	Stress Relief (SR)	AB	10 + 10
			AN	AB	10 + 10
				SB	10 + 10
				SP	10 + 10
CT/ Porosity	90°	On Fatigue and on metallography samples	SR	AB	3
			AN	AB	3
				SB	3
				SP	3
Metallography + Density	90°	10 x 10 x 186 See Figure 6	AN	AB	3[1]
Fracture Toughness	0°	ASTM E399-19 See Figure 9	SR	EDM	5
			AN		5
	90°+90°		SR		5
			AN		5

Test	Orien-tation	Geometry/ Standard	Heat Treatment	Post Process	Amount of Samples
Roughness	0°	25 x 12.50 x 3 mm See Figure 13	AN	AB	1
	15°				1
	30°				1
	45°				1
	60°				1
	75°				1
	90°				1
	0°			SB	1
	0°			SP	1
	0°			MI	1
	45°			SB	1
	45°			SP	1
	45°			MI	1
	90°			SB	1
	90°			SP	6
	90°			MI	1
Powder	90°	Container with ~60g See Figure 14	No Heat	AB	1

WP 3300: Test plan for verification Scalmalloy

Test	Orien-tation	Geometry Standard	Heat Treatment	Post Process	Amount of Samples
Tensile	90°	DIN 50125 [RD6] See Figure 4	No Heat (NH)	AB	7
			HIP	AB	7
			AG	AB	7
		DIN 50125 [RD6] See Figure 3	AG	Milling (MI)	7 + 7
Fatigue	90°	DIN 50113 [RD22] See Figure 8	AG	AB	10 + 10
			AG	SB	10 + 10
			AG	SP	10 + 10
CT/ Porosity	90°	On Tensile (NH+AB), Fatigue and metallography samples	NH/ AG	AB/ SB/ SP	5
Metallo-graphy	90°	10 x 10 x 374 See Figure 6	AG	AB	3[2]
Density	N/A	20 x 20 x 20 mm See Figure 5	NH	AB	3
			HIP	AB	3
			AG	AB	3
			AG	MI	3
Fracture Toughness	0°	ASTM E399-19 [RD13] See Figure 9	AG	MI	5
	90°		AG	MI	5
	90° + 90°, See chp. 3.1		AG	MI	5

Test	Orien-tation	Geometry Standard	Heat Treatment	Post Process	Amount of Samples
Roughness	0°	50 x 30 x 3 mm See Figure 10		AB	1
	15°			AB	1
	30°			AB	1
	45°			AB	1
	60°			AB	1
	75°			AB	1
	90°			AB	1
	0°			MI	1
	45°			MI	1
	90°			MI	1
	0°			SB	1
	45°			SB	1
	90°			SB	1
	0°			SP	1
	45°			SP	1
	90°			SP	1
	0°			Surface Grinding	1
	45°			Surface Grinding	1
	90°			Surface Grinding	1
	90°	Curved Surface See Figure 12		AB	1
	90°			MI	1
Humidity Test	90°	50 x 30 x 3 mm See Figure 10		AB	1
				SB	1
				AB + SurTec650	1
				SB + SurTec650	1
Critical Feature Test	90°	n/a See Figure 15 and Figure 16		AB	1 + 1
Powder	90°	Container with ~60g See Figure 14	NH	AB	1

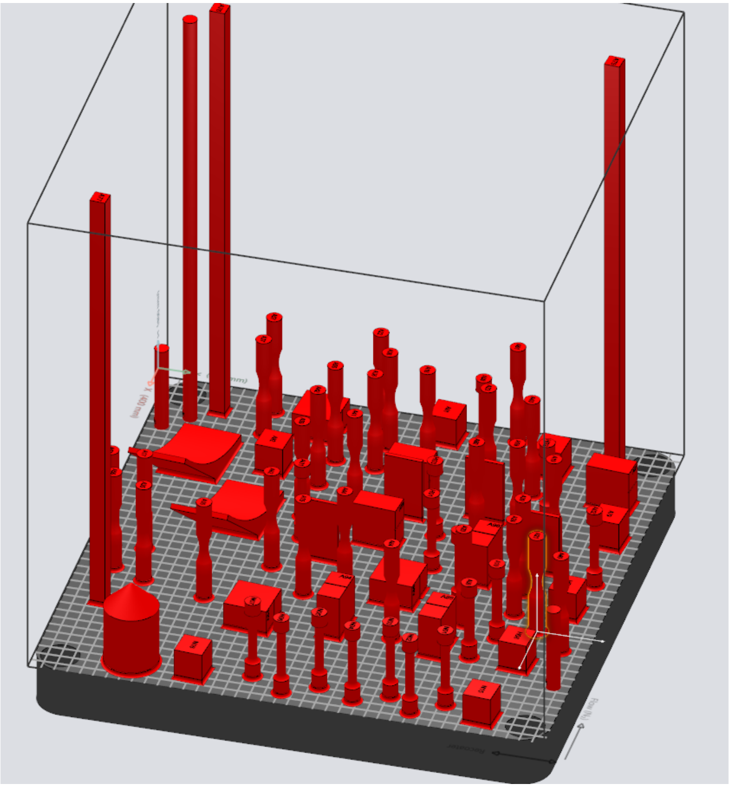
5. Design Maturation (Task 4)

WP 4100: Manufacturing + Testing of samples #1 (Feed Tower)

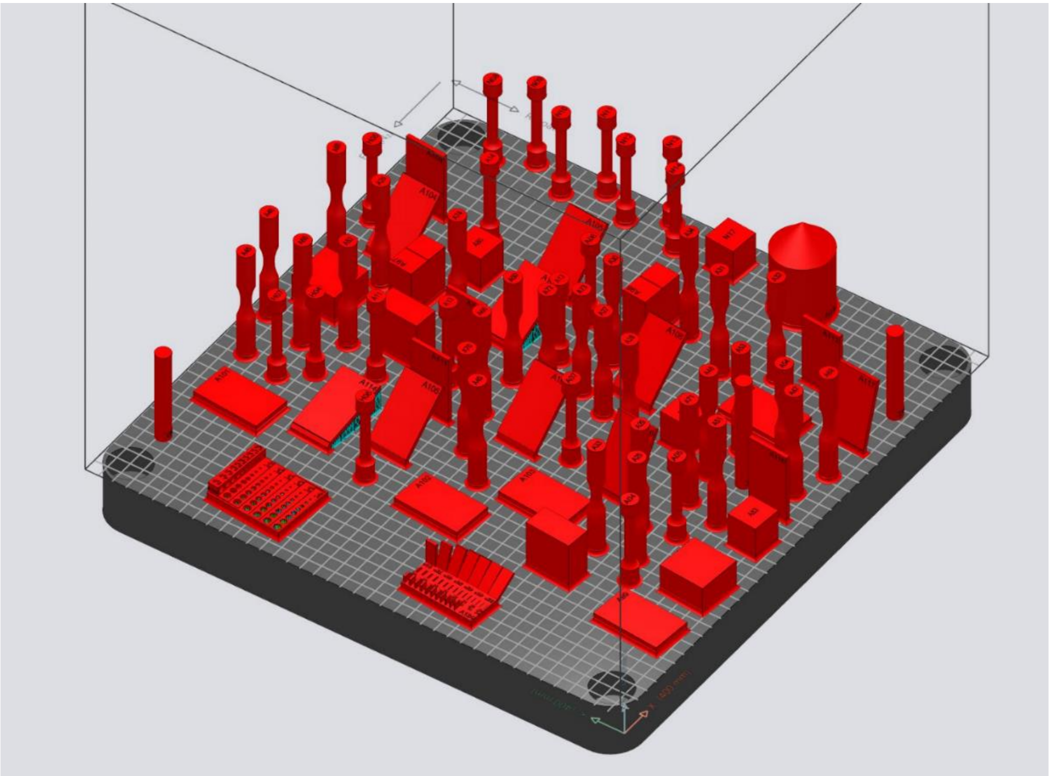
FHG IWS

WP 4200: Manufacturing + Testing of samples #2 (Antenna)

Manufacturing Samples acc. to Test plan using pAMPS



Build job 1

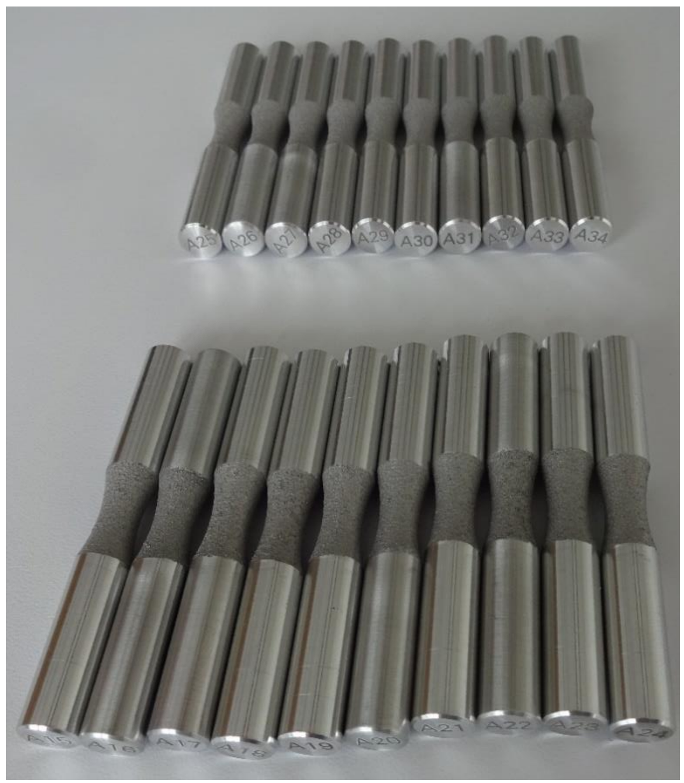


Build job 2

No process anomalies detected

WP 4200: Manufacturing + Testing of samples #2 (Antenna)

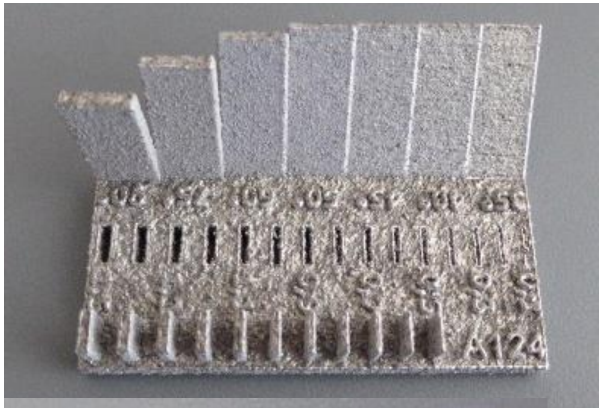
Tensile samples

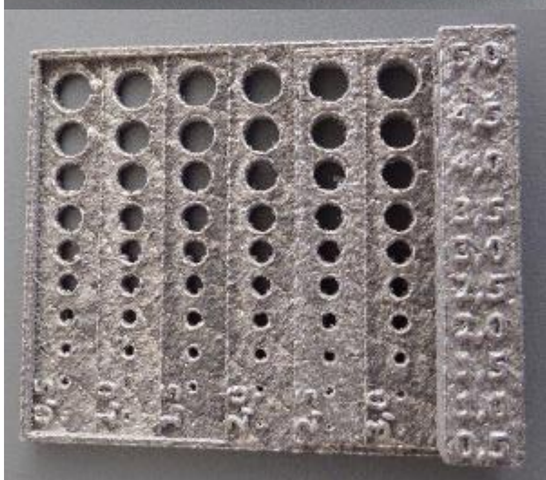


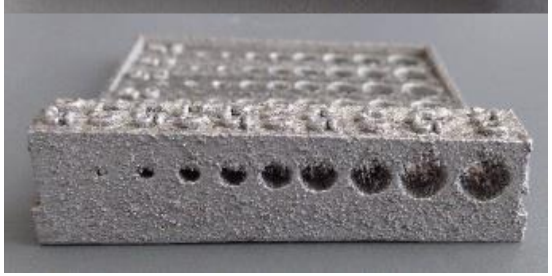
Fatigue samples

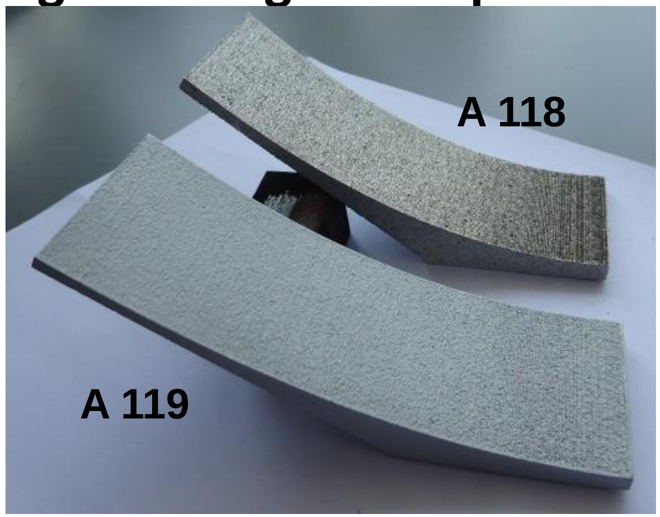
Fracture Toughness samples

WP 4200: Manufacturing + Testing of samples #2 (Antenna)









Sample ID	A118	A119
Condition	Aging	Aging
Surface Treatment	AB	Sand Blasted
Deformation Reflective Surface, max [mm]	0,71	0,57
Deformation Reflective Surface, min [mm]	-0,14	-0,17
Deformation other Surfaces, max [mm]	2,67	2,53
Deformation other Surfaces, min [mm]	-0,47	-0,33

→ Sand Blasting not suitable for RF applications

Humidity samples
(Test: 40C, 240h,
acc. ECSS-Q-ST-70-14C)
Top: No Surface Protection
Bottom: Surface Protection
→ No corrosion detected on all samples

WP 4200: Manufacturing + Testing of samples #2 (Antenna)

Heat Treatment		N	A																		A+H
Surface Post Process		AB	AB				SB				SP			SG			Mi				AB
Surface Passivation		N	N			S	N			S	N			N			N				N
Orientation [°]		90	0	45	90	90	0	45	90	90	0	45	90	0	45	90	0	45	90	90+90	90
$R_{p0.2}$ [Mpa]	Mean	270	-	-	470	-	-	-	-	-	-	-	-	-	-	-	-	-	487	-	465
	A *	199	-	-	439	-	-	-	-	-	-	-	-	-	-	-	-	-	466	-	441
	B	233	-	-	455	-	-	-	-	-	-	-	-	-	-	-	-	-	477	-	453
R_m [Mpa]	Mean	366	-	-	506	-	-	-	-	-	-	-	-	-	-	-	-	-	522	-	504
	A *	354	-	-	491	-	-	-	-	-	-	-	-	-	-	-	-	-	491	-	463
	B	360	-	-	507	-	-	-	-	-	-	-	-	-	-	-	-	-	507	-	483
E [Mpa]	Mean	63545	-	-	69079	-	-	-	-	-	-	-	-	-	-	-	-	-	65114	-	69767
A [%]	Mean	23,7	-	-	11,9	-	-	-	-	-	-	-	-	-	-	-	-	-	12,5	-	14,0
Density [g/cm³]	Mean	2,71	-	-	2,70	-	-	-	-	-	-	-	-	-	-	-	-	-	2,67	-	2,69
Porosity [%]	Mean	0,005%	-	-	0,004%	-	-	-	0,002%	-	-	-	0,004%	-	-	-	-	-	-	-	-
Ra [µm]	Max	-	31,33	22,11	16,67	-	18,65	11,38	8,68	-	18,38	13,36	7,76	0,88	0,76	0,91	0,28	0,33	7,87	-	-
Rq [µm]	Max	-	41,02	27,48	21,31	-	23,19	14,56	10,65	-	23,70	16,42	9,55	1,16	1,18	1,15	0,37	0,41	9,79	-	-
K1C	Mean	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	32,08	-	29,94	32,58	-
$\sigma_{D(10^6)}$ [Mpa]	Mean	-	-	-	100	-	-	-	125	-	-	-	175	-	-	-	-	-	-	-	-
Humidity	-	-	-	-	No	No	-	-	No	No	-	-	-	-	-	-	-	-	-	-	-

Abbreviations: N = Non; A = Aging; A+H = Aging + HIP; AB = As-Build; Mi = Milled; SB = Sand Blasted; SP = Shot Peening; SG = Surface Grinding; S = SurTec 650

Remark: * A-basis values only for comparision due to low number of samples

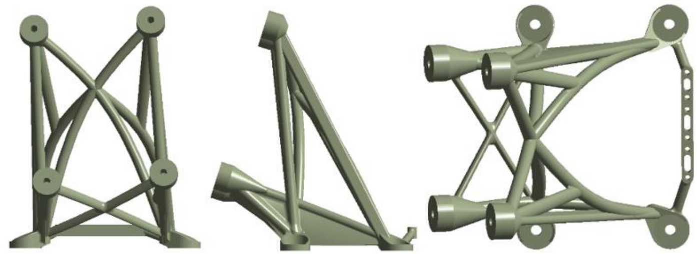
WP 4300: Preliminary Design + Analysis of Demonstrator 1 & 2

First Design modified taking into account results of material test campaigns

Factor of Safety:

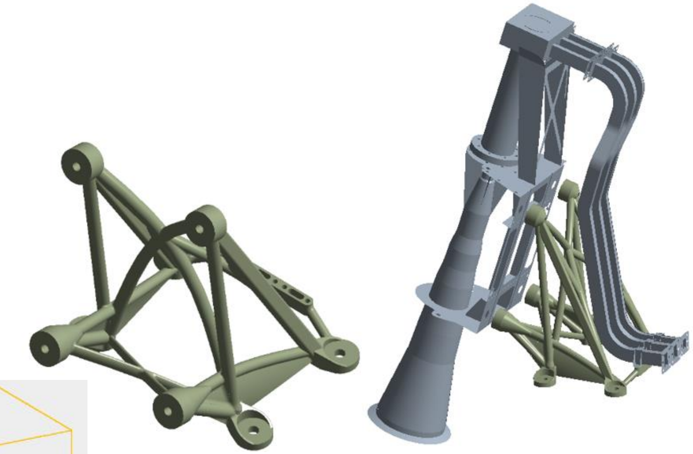
Factor	Value	Comment
Model Factor KM	1,20	
Project Factor	1,20	
Factor of Safety Yield FoSY	1,10	
Factor of Safety Ultimate FoSU	1,25	
Mass Margin	20%	Increase of density

WP 4300: Preliminary Design + Analysis; Feed Tower



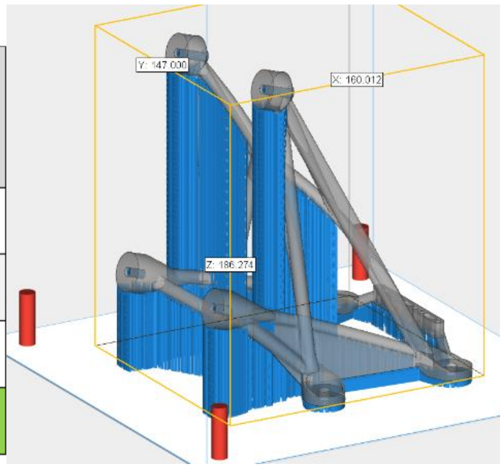
Results Summary:

	H2NBA, [RD3]	Optimized	Remark
Material	Aluminum	Ti6Al4V	-
Mass	840 g (w/o mass margin)	578 g (w/o mass margin)	262 g saving
Modal, 1st EF	161.4 Hz	161.3 Hz	-
Modal, 2nd EF	181.2 Hz	200.9 Hz	-
QSL, max. stress of all analyses LC 1 - 10	66.7 N/mm² LC 5	66.7 N/mm² LC 3 MOS > 0	-

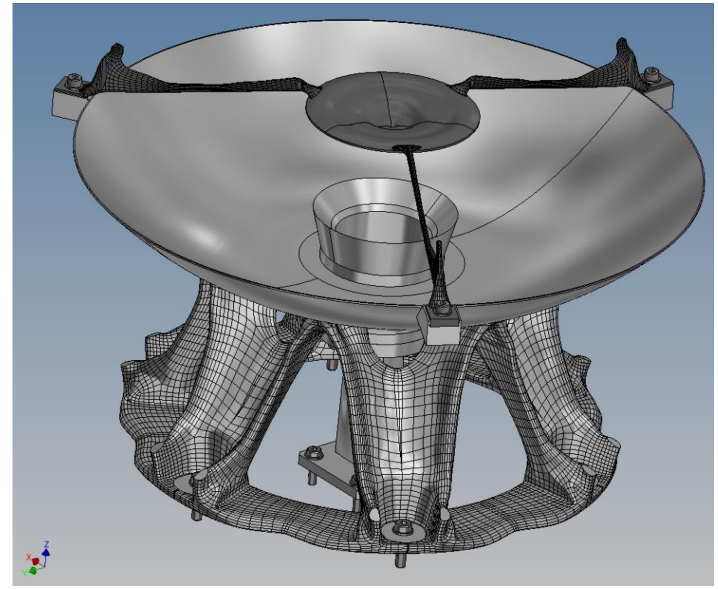


Evaluation of AM Manufacturability:

Parameter	S/W Target: Minimize Z-Height	S/W Target: Minimize Support surface	S/W Target: Minimize XY scan surface	Manual orientation
Z- Height [mm]	129	227	209	186
Support surface [mm²]	11.433	3.302	6.548	5.787
XY surface to scan [mm²]	1.391	555	400	696
Support Volume [mm³]	826.282	436.174	504.226	206.634

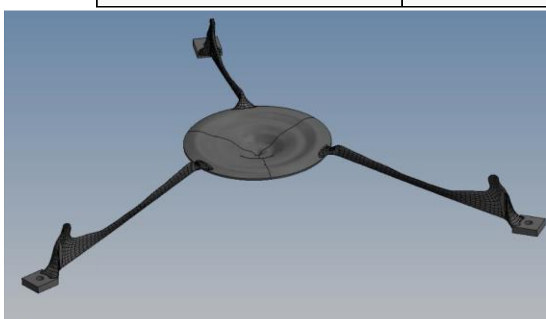


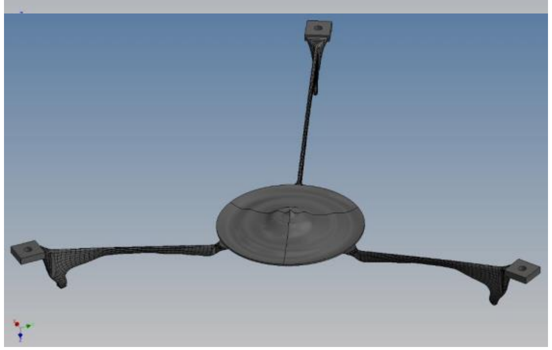
WP 4300: Preliminary Design + Analysis; Antenna

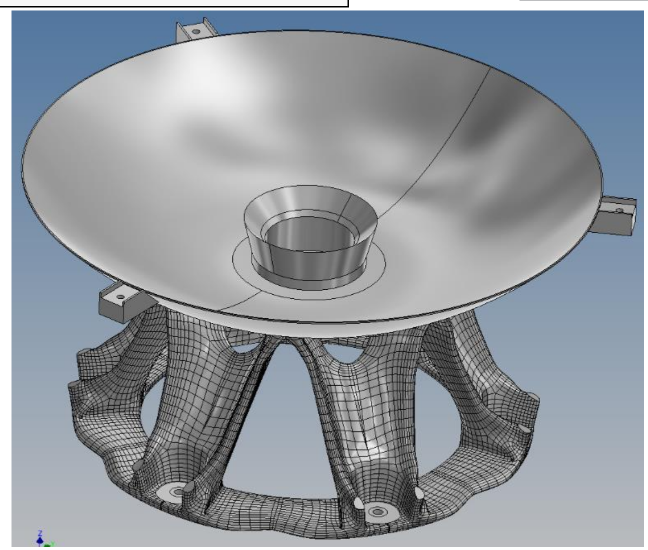


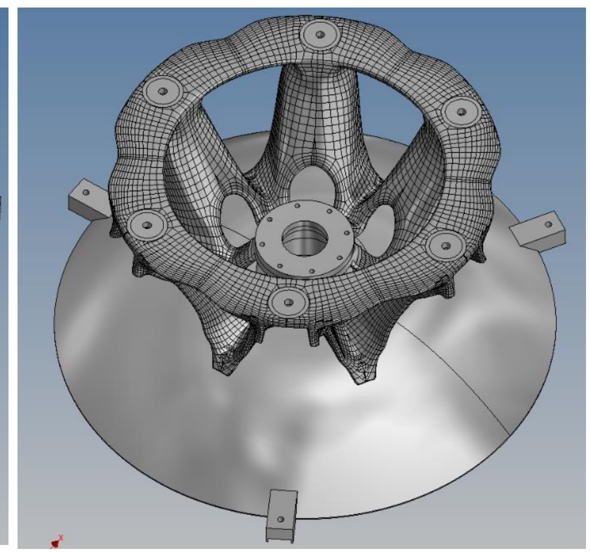
Results Summary:

	X-Band Antenna	Remark
Mass	2,11 kg	Including 20% mass margin; High potential for mass reduction
Modal, 1st EF	303,7 Hz	-
Modal, 2nd EF	304,8 Hz	-
QSL, max. stress of all analyses LC 1 - 26	44,6 N/mm²	High potential for mass reduction





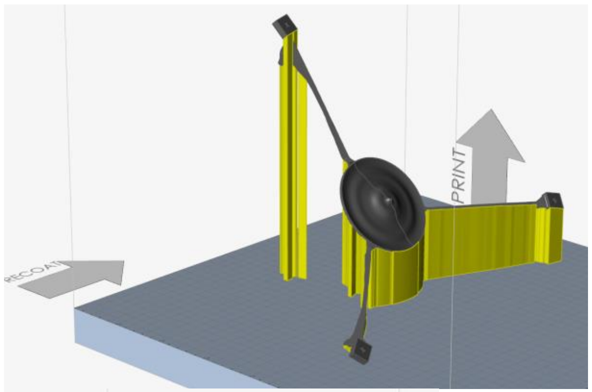


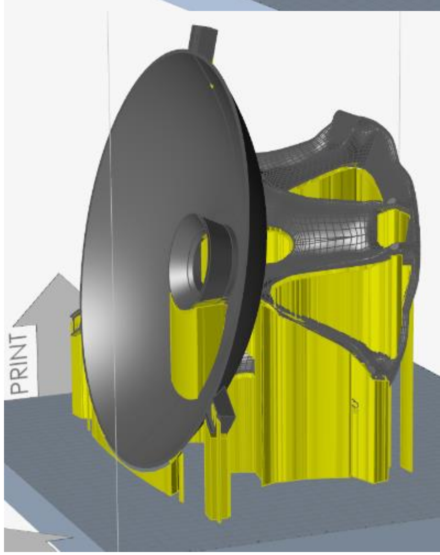


WP 4300: Preliminary Design + Analysis; Antenna

Evaluation of AM Manufacturability:

Software solution:

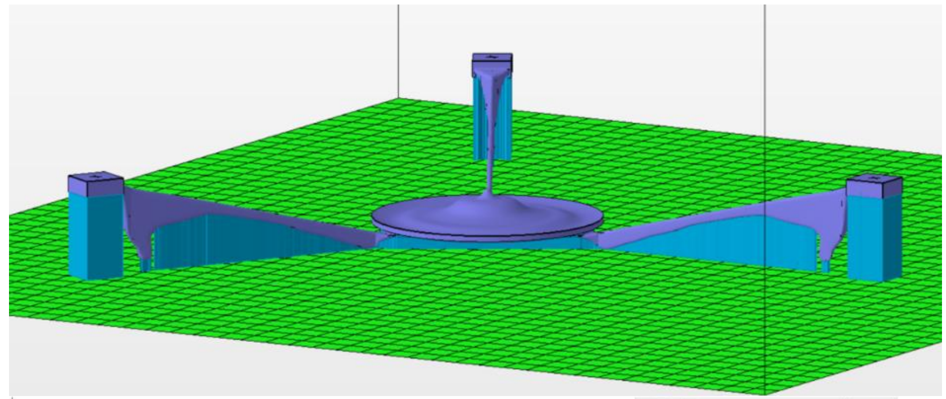


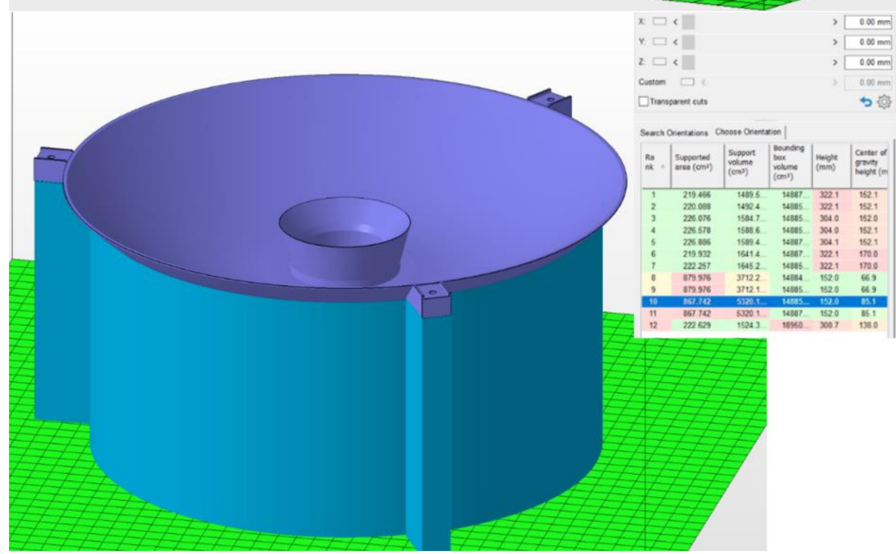


low deformation

low support material

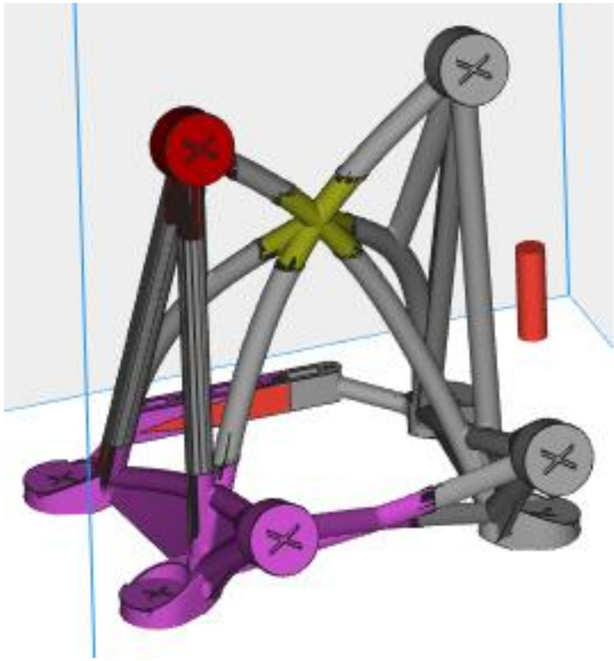
AM supplier solution:





6. Verification of AM Process (Task 5)

WP 5100/WP 5400: AM Verification, B/B Manufacturing & Evaluation #1

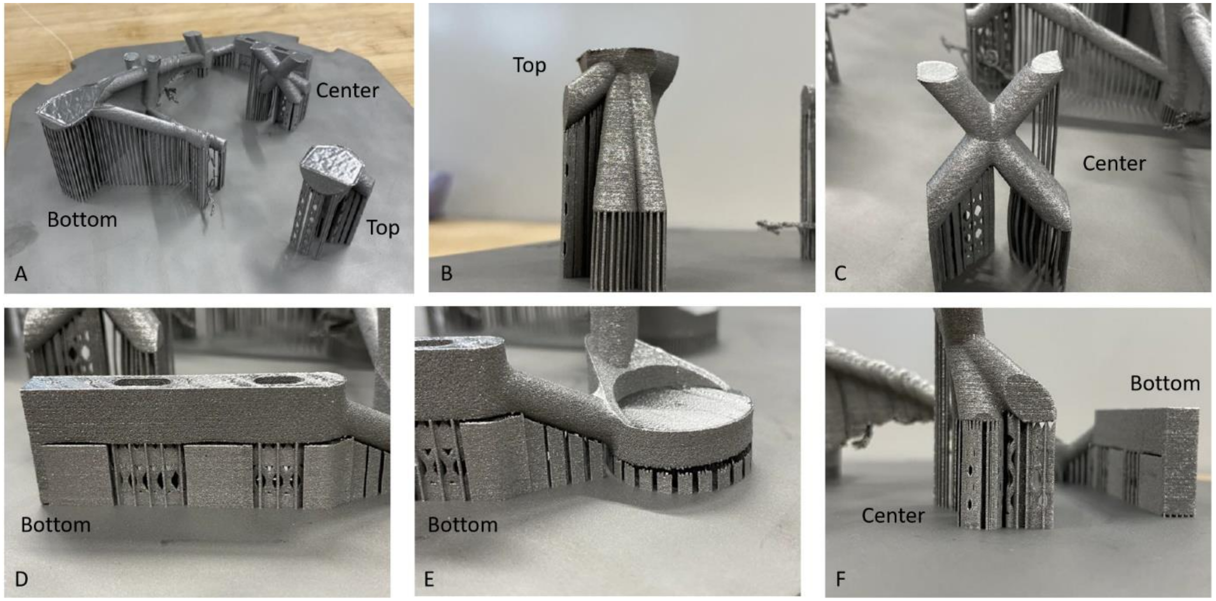


Feed Tower B/B (FHG IWS & HPS)

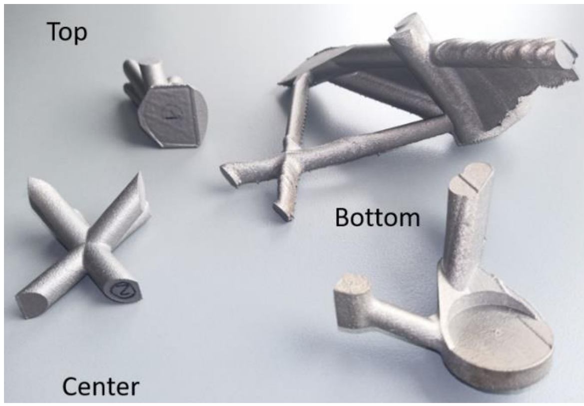
Selection criteria of relevant areas

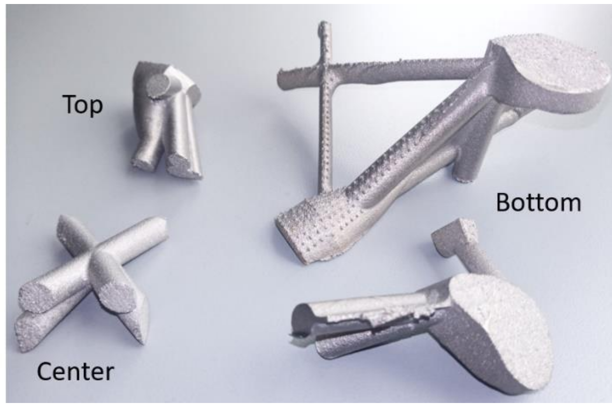
- Stress peaks (relevant for Bottom BB)
- Complex intersections (relevant for Center and Bottom BB)
- High distance from Build plate (risk of porosity)

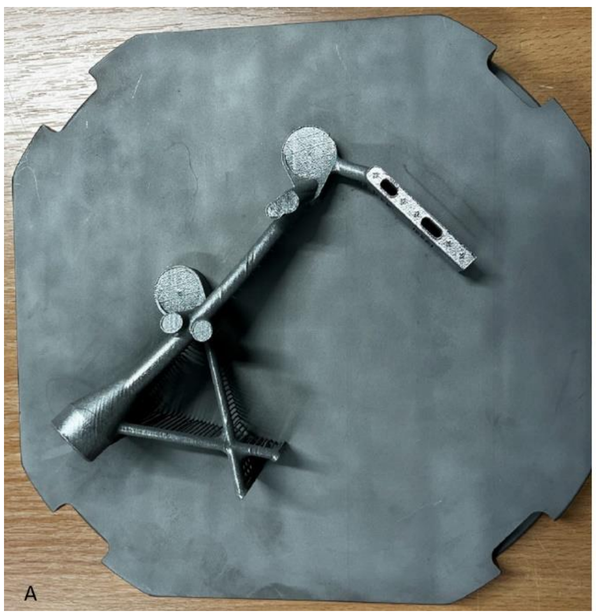
Manufacturing done bei FHG IWS using pAMPS 1

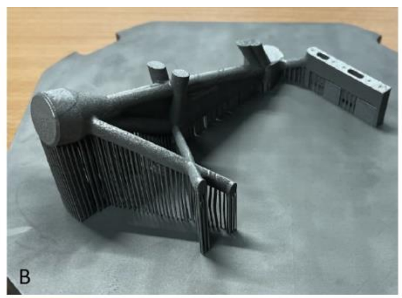


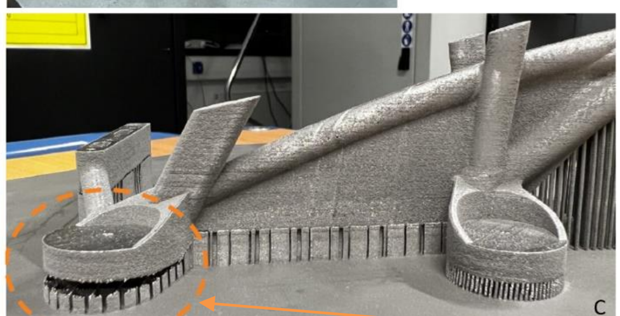
WP 5100/WP 5400: AM Verification, B/B Manufacturing & Evaluation #1











B/B Post Processed:
- stress relief
- support removal
- sand blasting

Visual Inspection:
- Some non-critical marks on surfaces
- No visual cracks

Dimensional Check:
- Deviations +- 0.1mm, in some areas higher

CT-Scan:
- Porosity < 0.01%

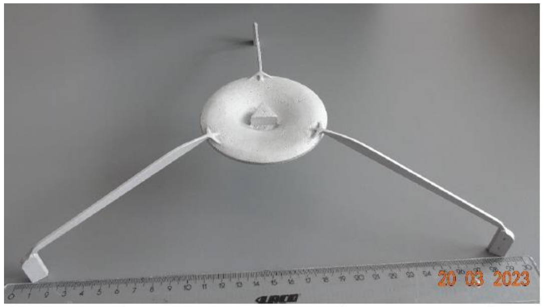
Check for α-case:
- No α-case detectable

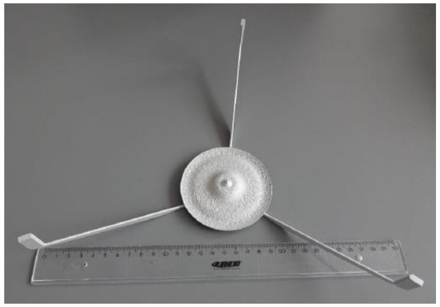
→ AM Parameter set well defined
→ pAMPS became AMPS

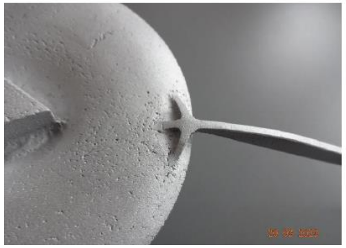
Support too weak→ Modified

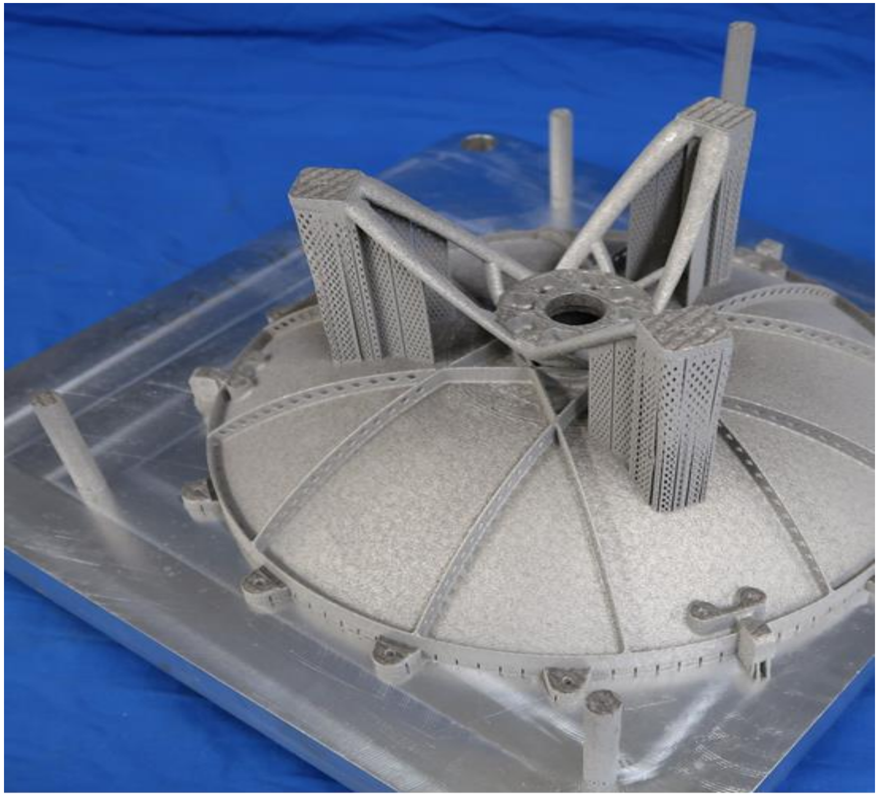
WP 5200/WP 5400: AM Verification, B/B Manufacturing & Evaluation #2

PDR design modified to „Pre-CDR“ design
to reduce amount of material

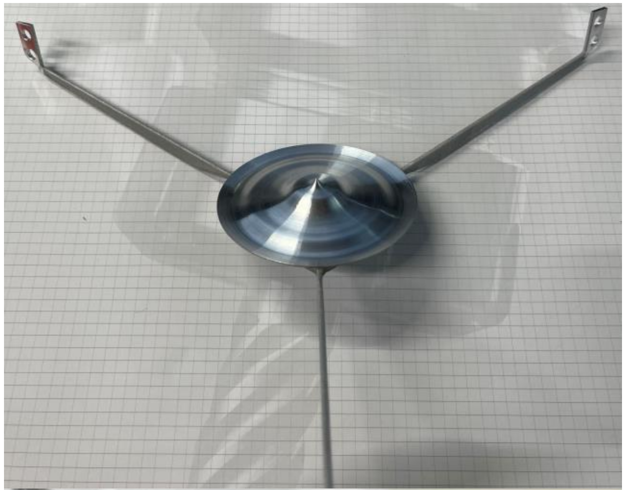


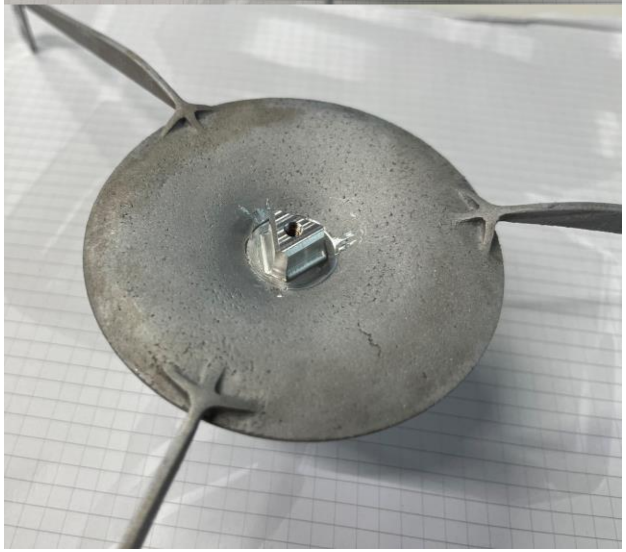


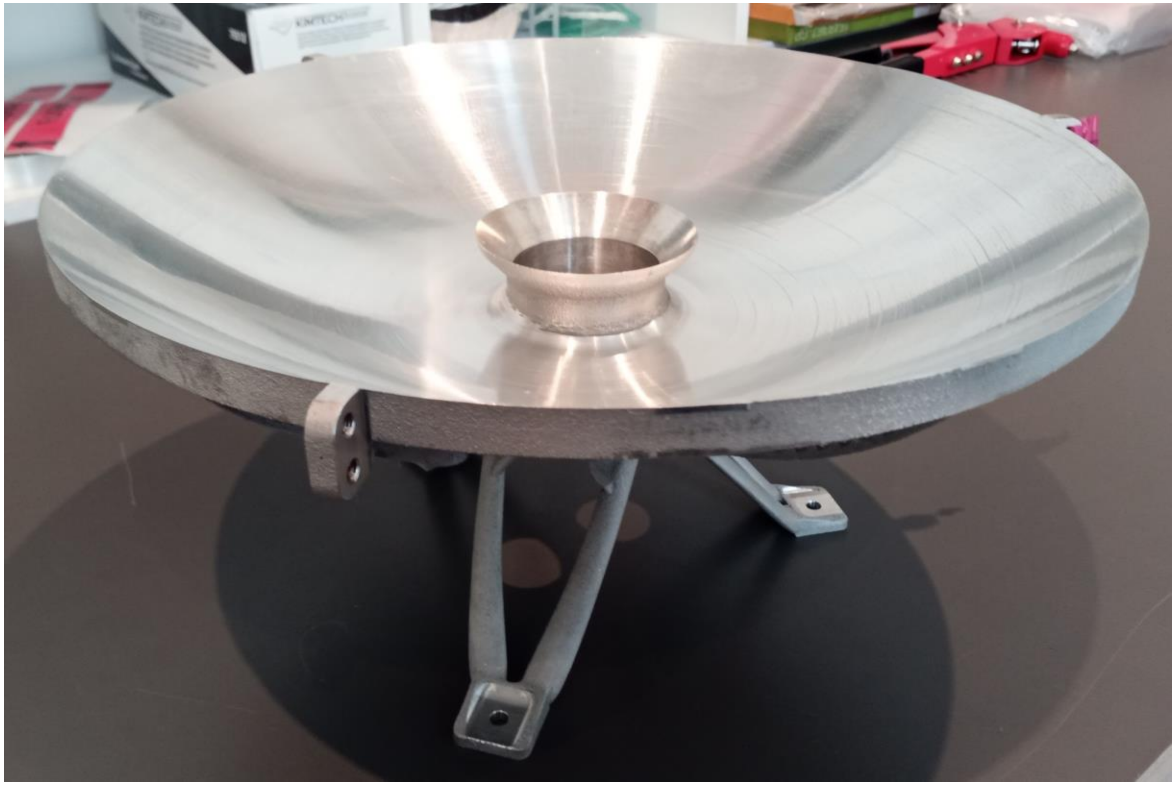




WP 5200/WP 5400: AM Verification, B/B Manufacturing & Evaluation #2







WP 5200/WP 5400: AM Verification, B/B Manufacturing & Evaluation #2

Visual inspection:

- Smooth surface of post-processed surfaces
- Circumferential tracks have no influence on RF performance
- Cracks on struts visible caused by tool collision

→ Post-process to be improved

Dimensional check:

- Measurement with Laser Radar
- Deviation: Main reflector RMS = 0.14mm (acceptance < 0.08mm)
  Sub-Reflector RMS = 0.07mm (acceptance < 0.04mm)

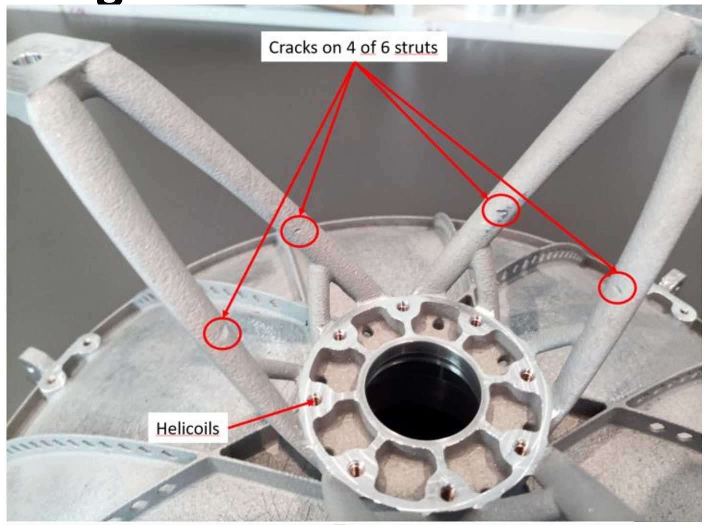
→ Milling process to be improved

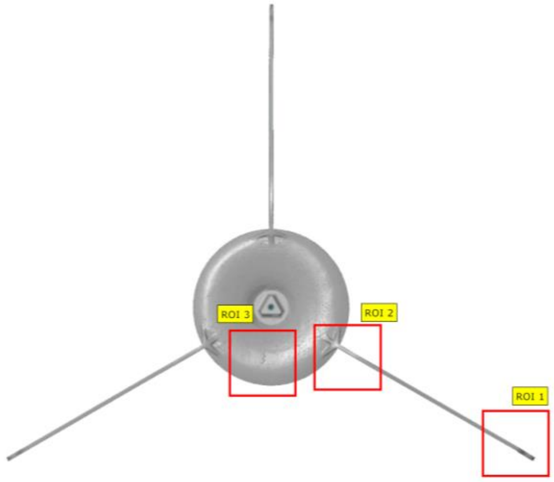
CT-scan of relevant areas:

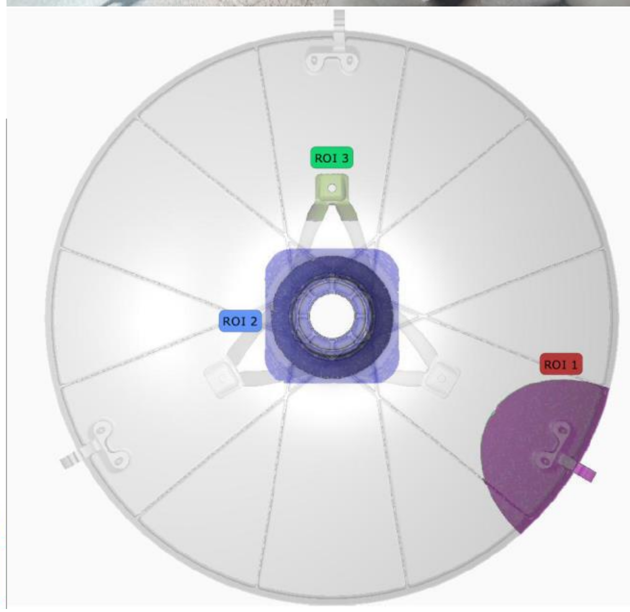
- 3 regions of interest (ROI) identified
- Porosity < 0.02%

→ AM Parameter set well defined

→ pAMPS became AMPS

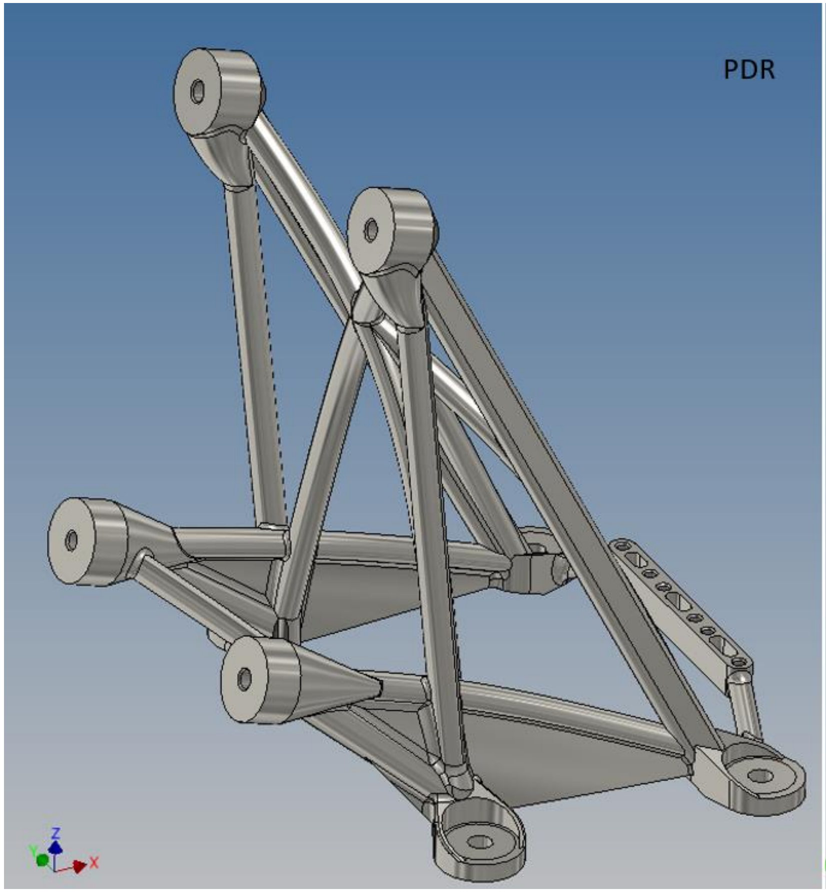


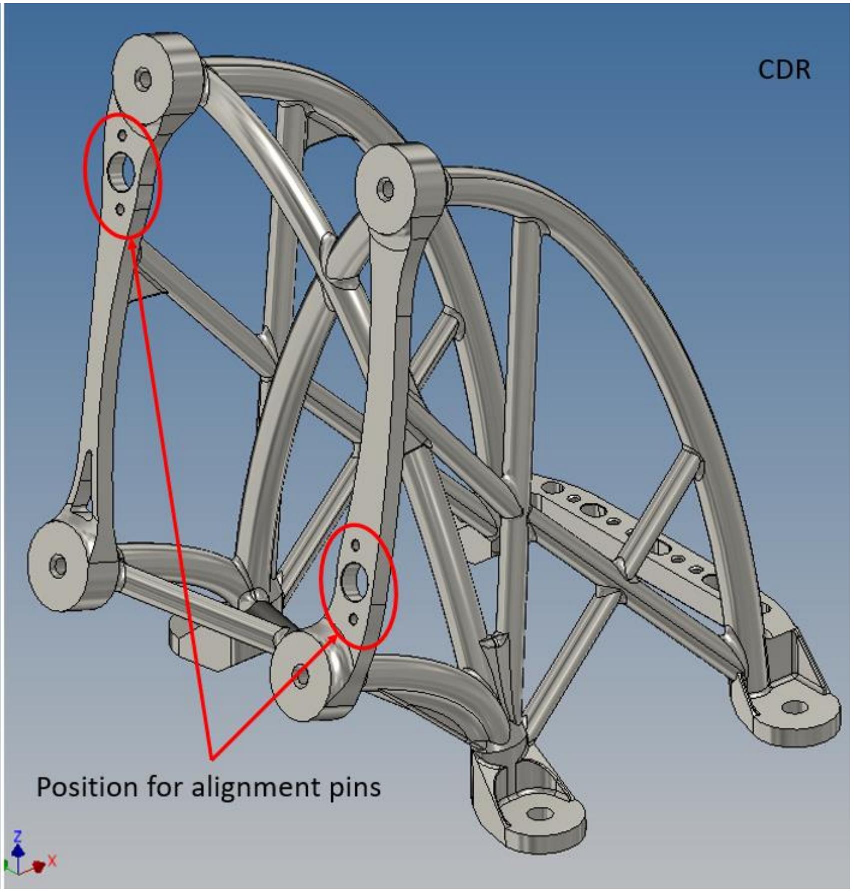




WP 5400: Final Design of Demonstrators #1

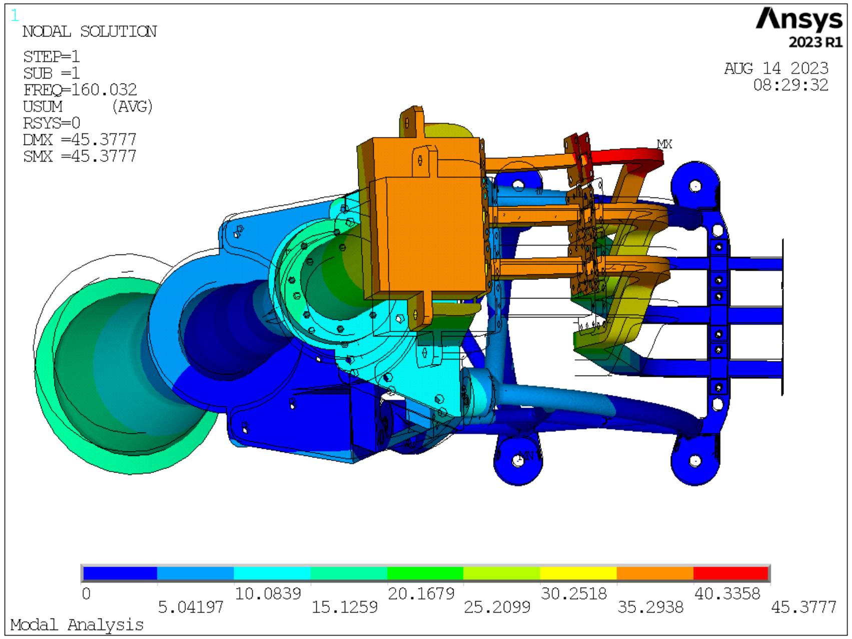
Feed Tower

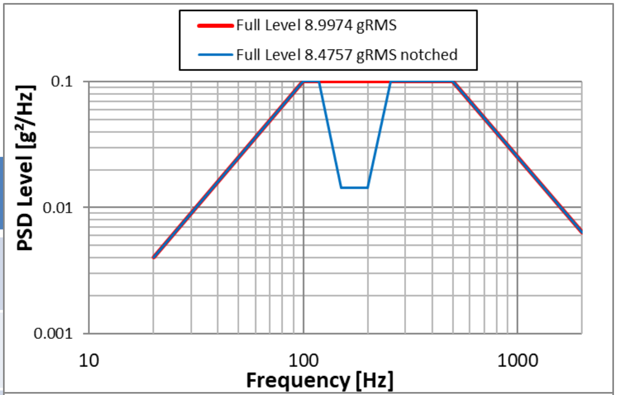


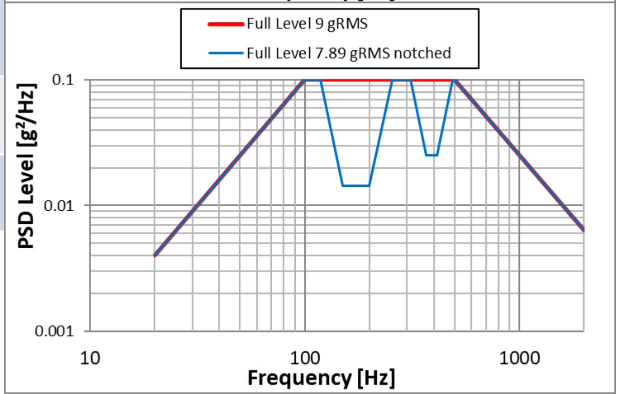


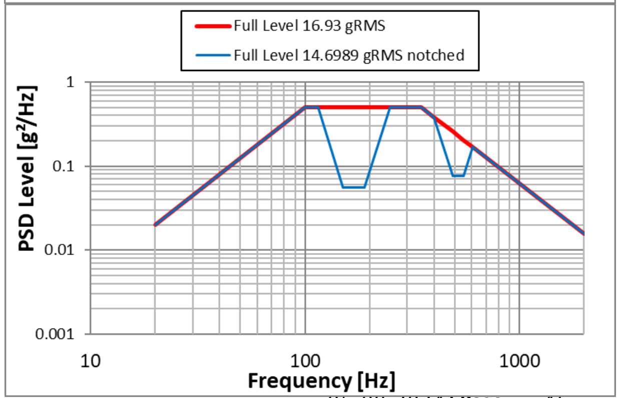
WP 5400: Final Design of Demonstrators #1

Analysis	Requirement	Result	Comment
Modal	> 100Hz	X/Z = 162,9Hz; Y = 160 Hz	
QSL	MoS > 0	MoS Min = 8.57	
Sine	MoS > 0	n/a	First eigenmode > 100Hz
Random	MoS > 0	MoS Min = 0.22	Spectra notched
TED	MoS > 0	MoS Min = 0.23	



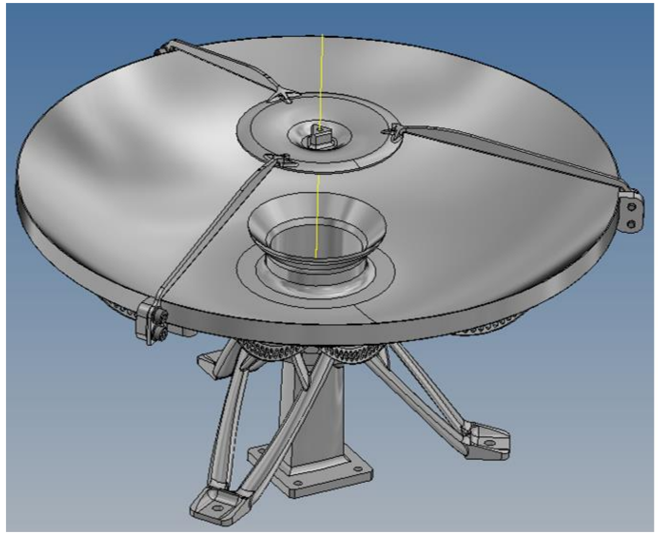


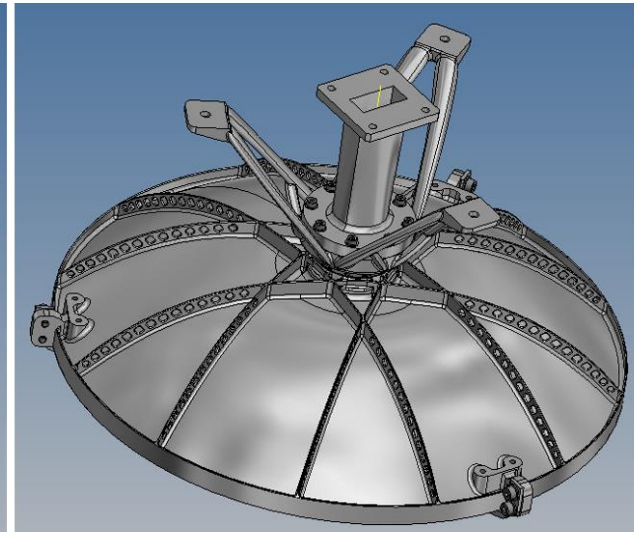




WP 5400: Final Design of Demonstrators #2

Breadboard (mass 849g)





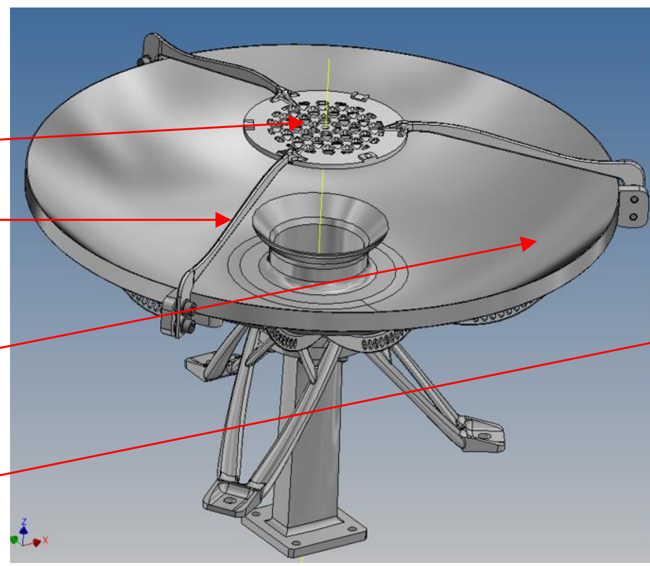
CDR (mass 689g)

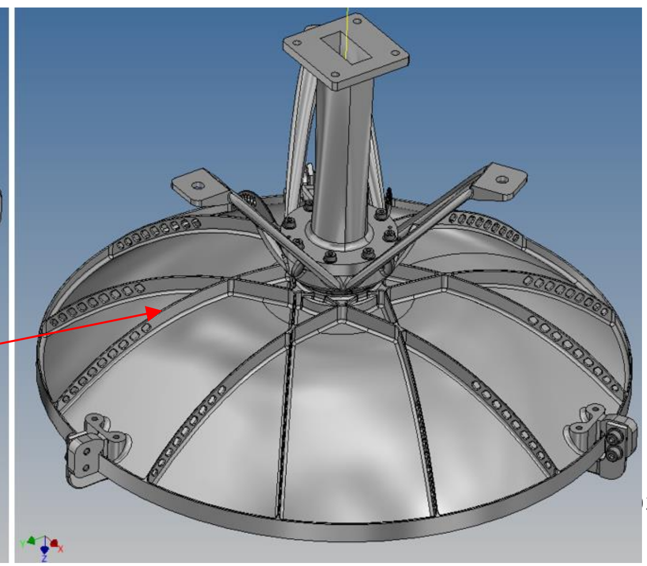
Sub-Reflector:

- Isogrid pattern
- Stiffer struts

Main Reflector:

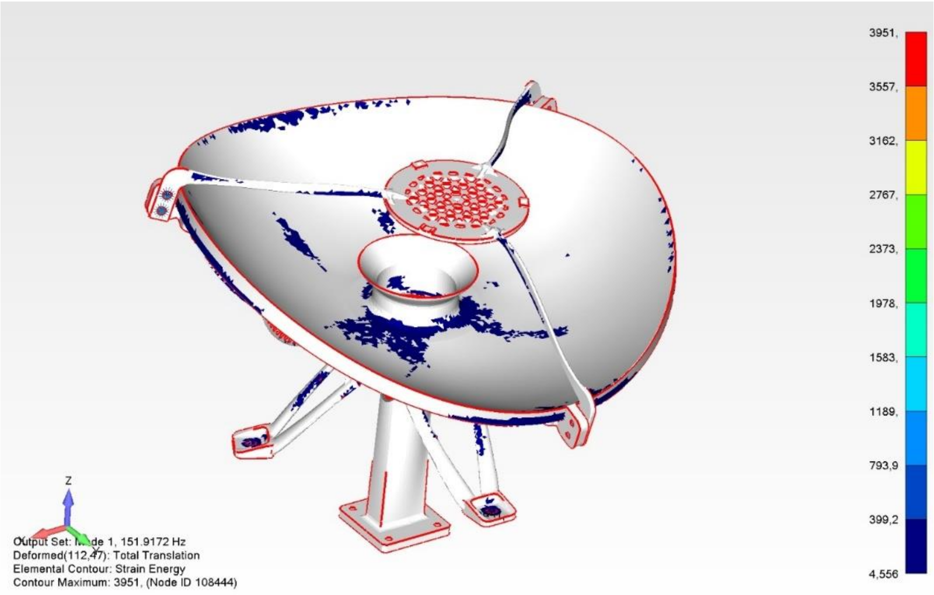
- Reduced thickness on reflective surface
- Removal holes in ribs





WP 5400: Final Design of Demonstrators #2

Analysis	Requirement	Result	Comment
Modal	> 100Hz	X: 151.92 Hz; Y: 151.98 Hz; Z 166.64 Hz	
QSL	MoS > 0	MoS Min = 3.72	
Sine	MoS > 0	n/a	First eigenmode > 100Hz
Random	MoS > 0	MoS Min = 0.33	Spectra notched
TED	MoS > 0	MoS Min = 0.88	



WP 5300: Test Plan on Demonstrators

Feed Tower:

Sequenz	Test	Frequency	Peak	Slope
1	Low Level Sine (sweep)	5 – 2000 Hz	0,2 g	2 oct/min
2	Qualification Level Sine	5 – 100 Hz	Max. 20 g	2 oct/min
3	Low Level Sine (sweep)	5 – 2000 Hz	0,2 g	2 oct/min
4	Intermediate Level Random	5 – 2000 Hz	-5 dB	60 s
5	Low Level Sine (sweep)	5 – 2000 Hz	0,2 g	2 oct/min
6	Qualification Level Random	5 – 2000 Hz	OOP: 16,9 g rms IP: 9,0 g rms	120 s
7	Low Level Sine (sweep)	5 – 2000 Hz	0,2 g	2 oct/min

QSL

Parameter	Value
Frequency [Hz]	36
Acceleration X [g]	20
Acceleration Y [g]	20
Acceleration Z [g]	20

Sine

Axis	Frequency [Hz]	Level
All axis	5 – 22.3 22.3 – 100	± 10 mm ± 20 g

Random

OOP		IP	
f (Hz)	Load	f (Hz)	Load
20 - 100	+ 6 dB/oct	20 - 100	+ 6 dB/oct
100 - 350	0.5 g^2/Hz	100 - 500	0.1 g^2/Hz
350 - 2000	- 6 dB/oct	500 - 2000	- 6 dB/oct
Total g_{RMS}	**16.9 g**	**Total g_{RMS}**	**9.0 g**

WP 5300: Test Plan on Demonstrators

TVAC: 10 cycles

Temperature range +150 [+5/-0] to -150°C [+0/-5]

Heating and cooling rate 5-6 K/min

Dwell time at extremes 15 minutes

Atmosphere LN2 40 mbar.

Feed Tower Witness Samples

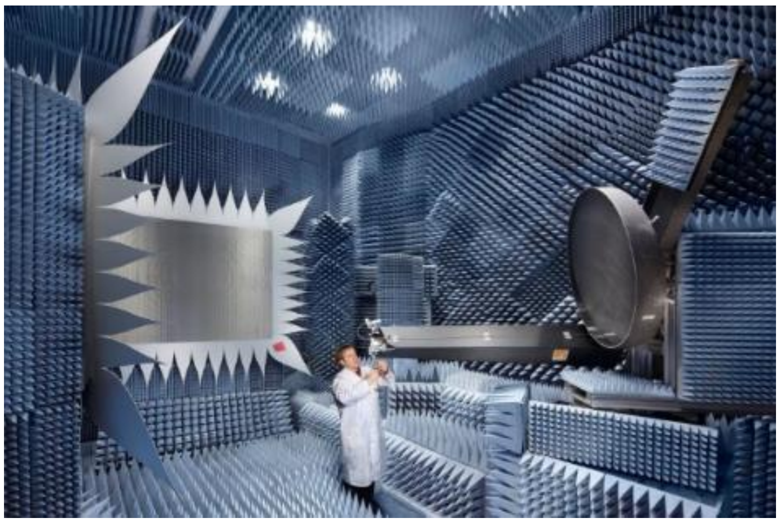
Samples Geometry	Amount	Post-Processing Step	Test Standard Test Facility
Tensile samples	3 (1 spare)	Heat Treatment Milling/ Turning Thread Cutting	Tensile Test DIN EN ISO 6892-1 [RD7] FHG IWS
Full Height Bar	2	Heat Treatment Milling/ Turning	One stored and only tested in failure case Density Metallography Chemical composition FHG IWS
Powder Capture Sample	1 (~60g powder)	No heat treatment	Store, testing only in failure case

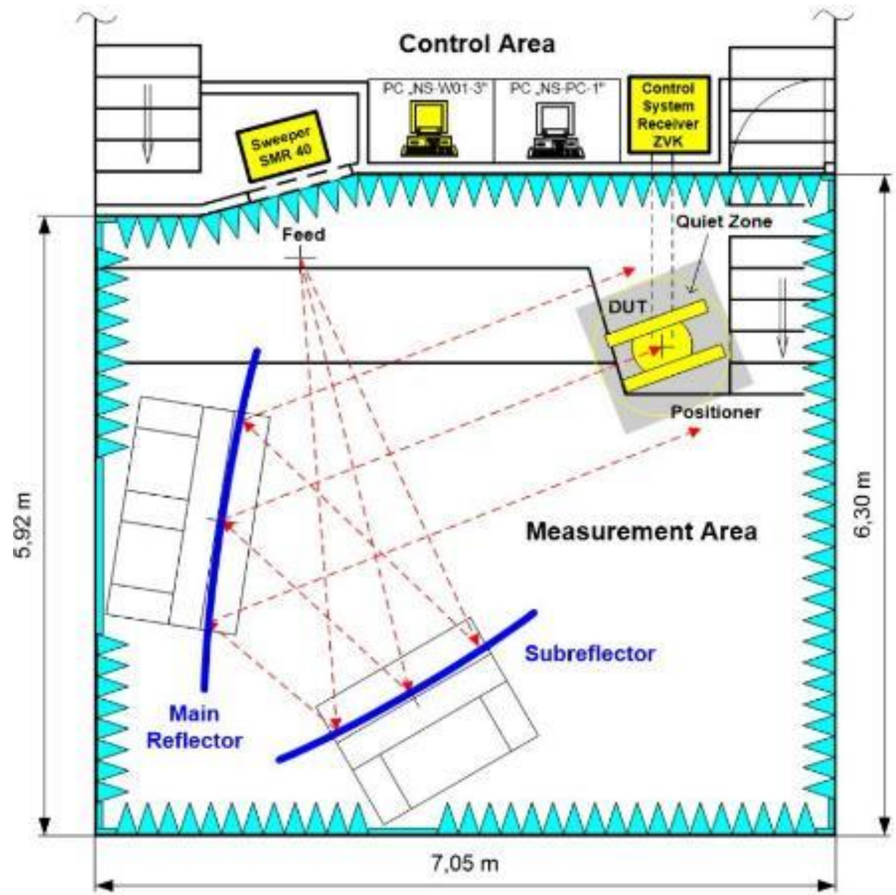
WP 5300: Test Plan on Demonstrators

Antenna

RF Performance Test:

- RF pattern measurements
- VSWR/Return Loss
- Peak Gain
- Antenna Gain at the edge of the coverage (half cone angle = 0.95°)
- Peak Cross polarization
- Facility: Compensated Compact Test Range (CCR), MUAS





WP 5300: Test Plan on Demonstrators

Antenna

Sequenz	Test	Frequency	Peak	Slope
1	Low Level Sine (sweep)	5 – 2000 Hz	0,2 g	2 oct/min
2	Qualification Level Sine	5 – 100 Hz	Max. 30 g	2 oct/min
3	Low Level Sine (sweep)	5 – 2000 Hz	0,2 g	2 oct/min
4	Intermediate Level Random	5 – 2000 Hz	-5 dB	60 s
5	Low Level Sine (sweep)	5 – 2000 Hz	0,2 g	2 oct/min
6	Qualification Level Random	5 - 2,000 Hz	21,4 g rms	120 s
7	Low Level Sine (sweep)	5 – 2000 Hz	0,2 g	2 oct/min

QSL

Parameter	Value
Frequency [Hz]	36
Acceleration X [g]	30
Acceleration Y [g]	30
Acceleration Z [g]	30

Sine

Axis	Frequency [Hz]	Level [g]	Sweep Rate [oct/min]
All axis	5 – 20 20 – 125	Max shaker amplitude 30	2

Random

Axis	Frequency [Hz]	Qualification Level
All (3 axis)	20 – 100	+12 dB/oct
	100 – 300	1.5 g^2/Hz
	300 – 650	-15 dB/oct
	650 – 850	0.03 g^2/Hz
	850 – 2000	-6 dB/oct
	g_{RMS}	**21.4**

WP 5300: Test Plan on Demonstrators

TVAC: 10 cycles

Temperature range +150 [+5/-0] to -150°C [+0/-5]

Heating and cooling rate 5-6 K/min

Dwell time at extremes 15 minutes

Atmosphere LN2 40 mbar

Feed + Antenna tested in one chamber

Antenna Witness Samples

Samples Geometry	Amount	Post-Processing Step	Test Standard Test Facility
Tensile samples	3 (1 spare)	Heat Treatment Milling/ Turning Thread Cutting	Tensile Test DIN EN ISO 6892-1 [RD7] FHG IWS
Full Height Bar	2	Heat Treatment Milling/ Turning	One stored and only tested in failure case Density Metallography Chemical composition FHG IWS
Powder Capture Sample	1 (~60g powder)	No heat treatment	Store, testing only in failure case

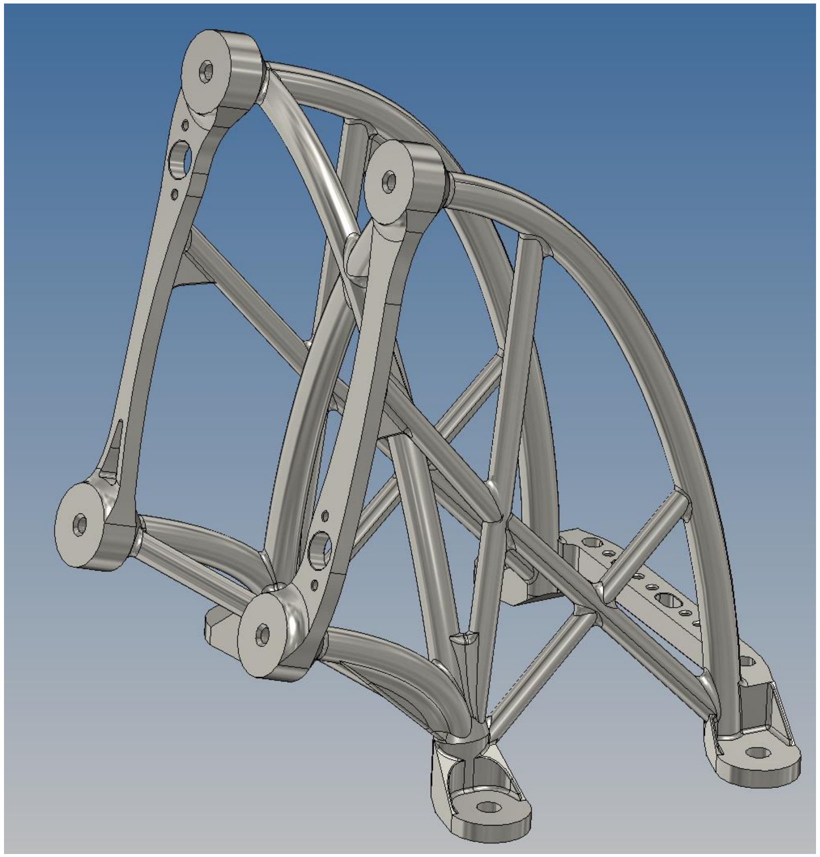
7. Demonstrator Manufacturing and Testing (Task 6)

WP 6100: AM of Demonstrator #1 (Feed Tower)

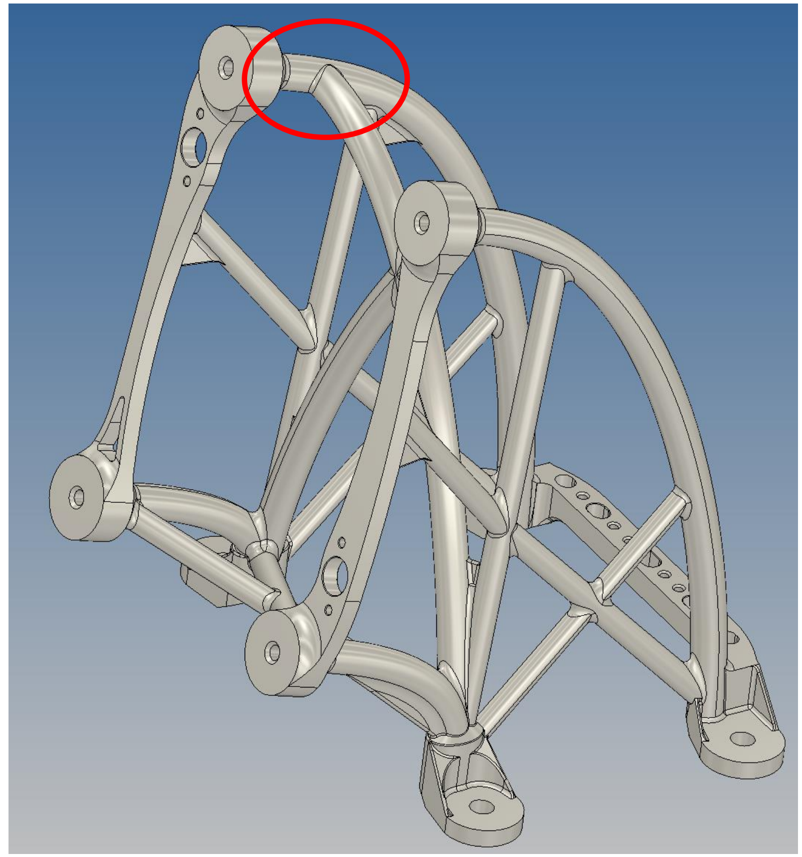
FHG IWS

WP 6100: Design Modifications Feed Tower

CDR

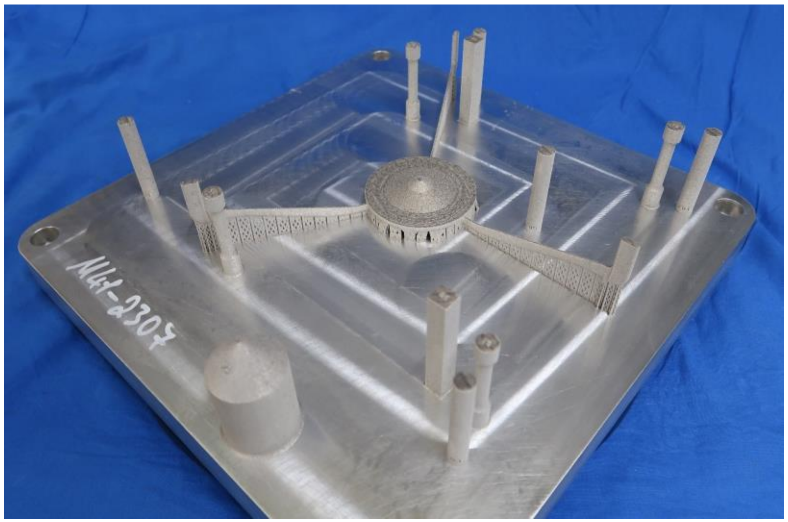


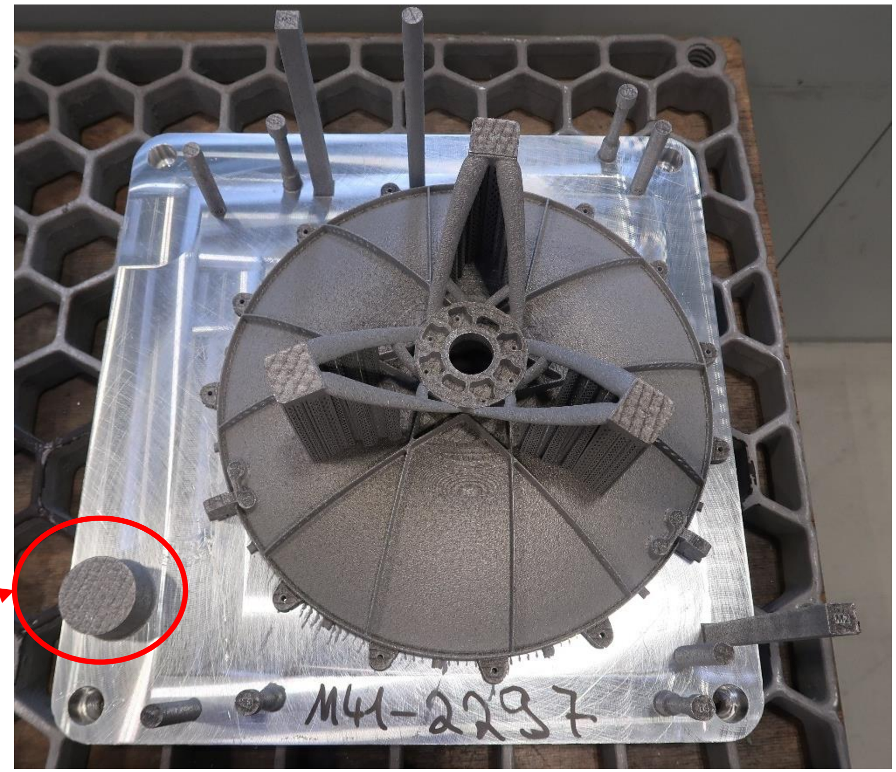
Demonstrator: Modification due to risk mitigation



WP 6200: AM of Demonstrator #2 (Antenna) – After AM

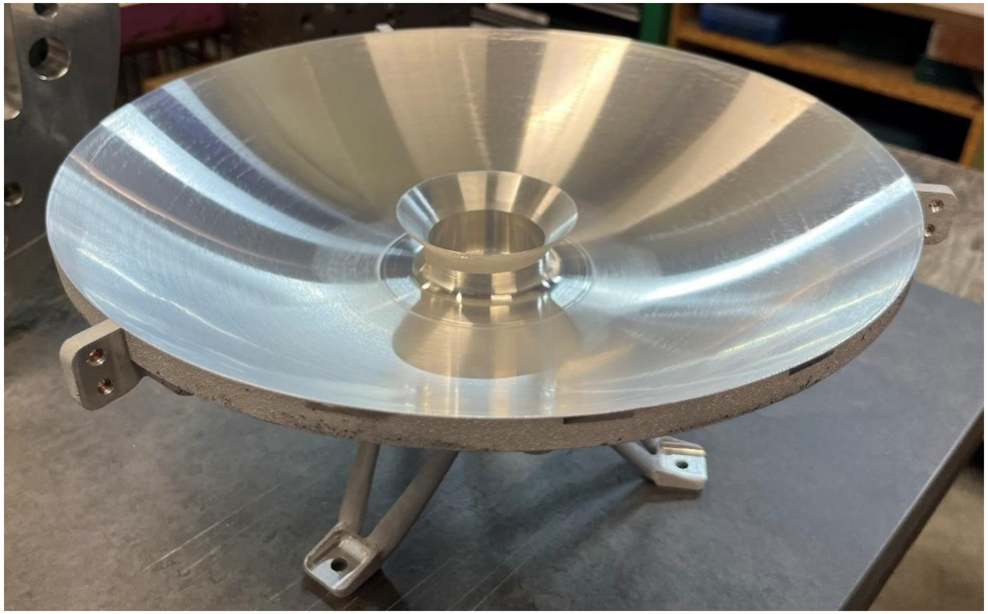
AMP 2 used for manufacturing Antenna demonstrator parts and witness samples





Manufacturing of powder container
failed due to error during job preparation
→ Powder extracted directly from finished build job

WP 6200: AM of Demonstrator #2 (Antenna) – After Post Processing



Steps:
- Heat treatment
- Sawing from build plate, support removal and sand blasting
- Mechanical post-processing (milling, hole drilling, implement inserts)
- Surface protection with Surtec 650

WP 6200: AM of Demonstrator #2 (Antenna) – Measurements

Part	Ref.	Nominal		Measured	
		Profile of any surface [mm]	RMS Deviation [mm]	Profile of any surface [mm]	RMS Deviation [mm]
Main-Reflector	[RD13]	0,02	≤ 0,08	0,259	0,109
Sub-Reflector	[RD14]	0,02	≤ 0,04	0,203	0,075

After internal check at HPS by RF engineers, deviations were accepted.

WP 6200: AM of Demonstrator #2 (Antenna) – Witness Samples

Tensile Tests:

- Main Reflector: T1 – T4
- Sub Reflector: T5 – T8

CT-Scan:

- Porosity < 0.01%

Metallography:

- Main Reflector: Porosity max. 0.25%
- Sub Reflector: Porosity max. 0.33%

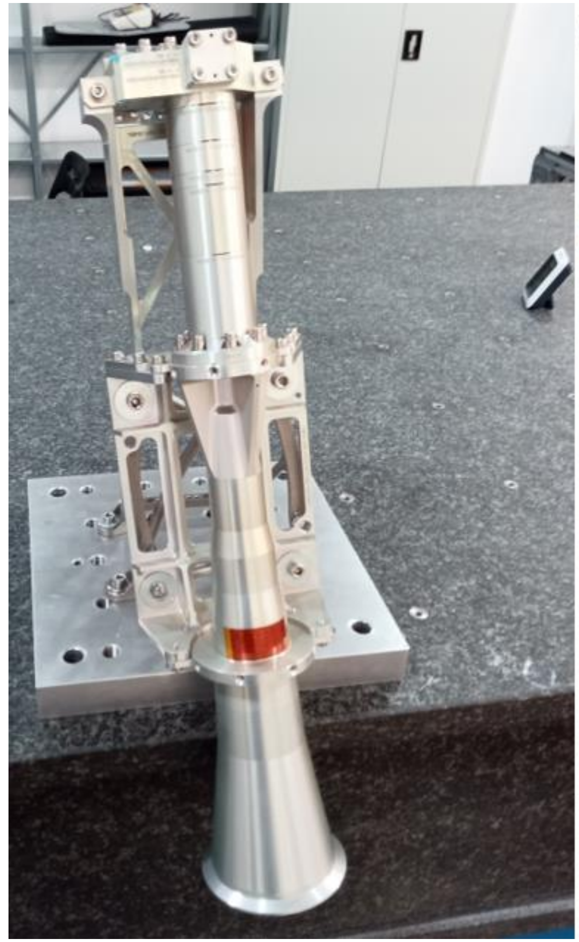
Samples	E [kN/mm²]	Rp0.2 [N/mm²]	Rm [kN/mm²]	A [%]	Comment
T1 – T4	68,656	501	527	11,16	Mean values
T5 – T8	67,935	495	522	11,39	Mean values
Material Test Campaign	65,114	487	522	12,5	Mean values
Success Criteria	n/a	> 450	> 490	> 8	[RD1]

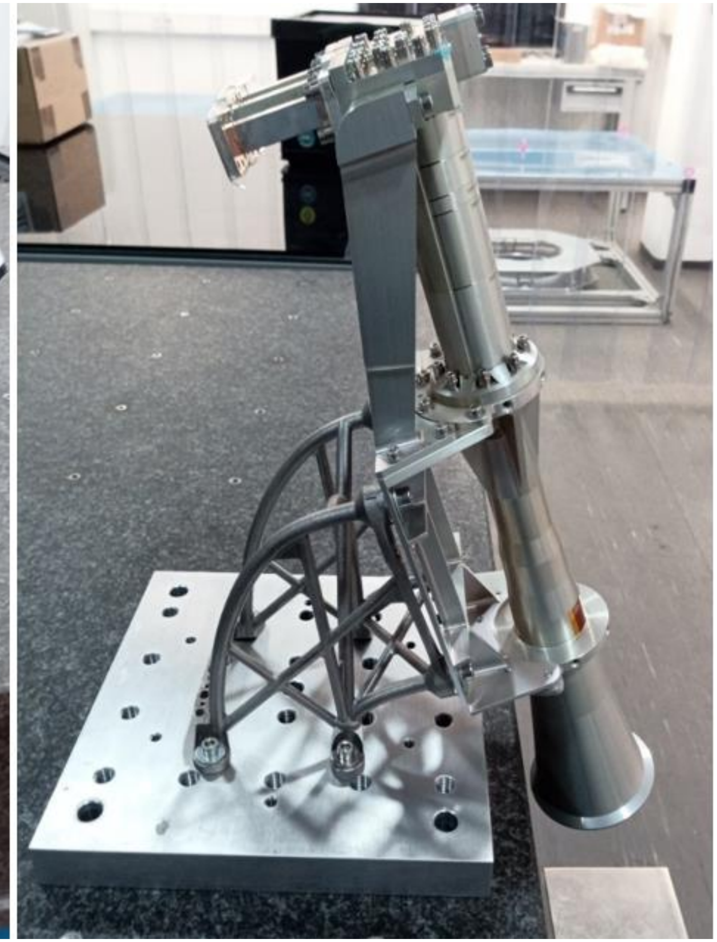
All results were acceptable → Start of Antenna Assembly

WP 6200: Assembly

Feed Assembly:

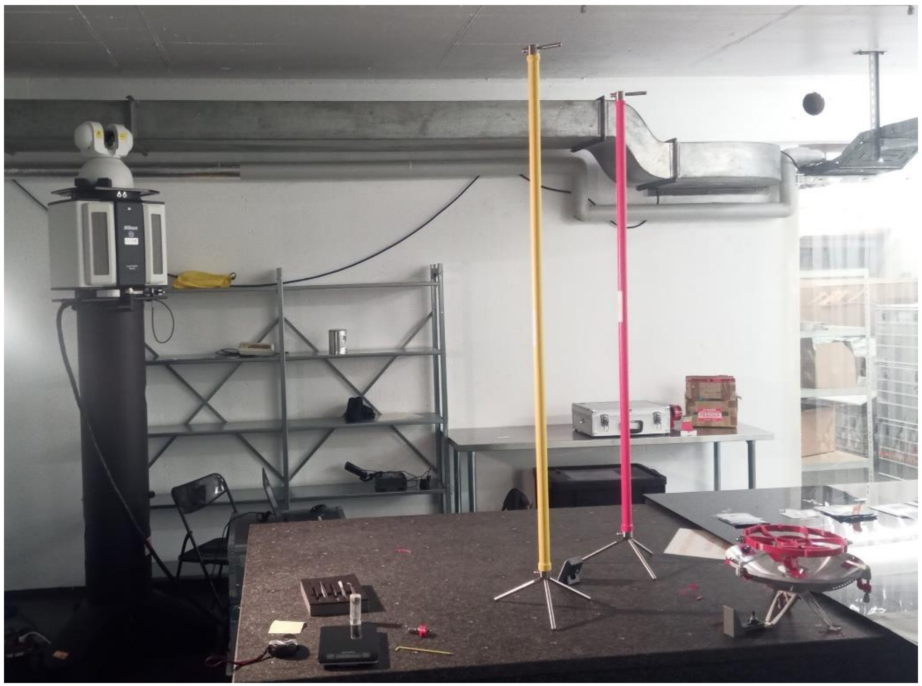
- Attachment Feed Chain (H2NBA engineering model) to Feed Tower
- No Alignment (reflector necessary)

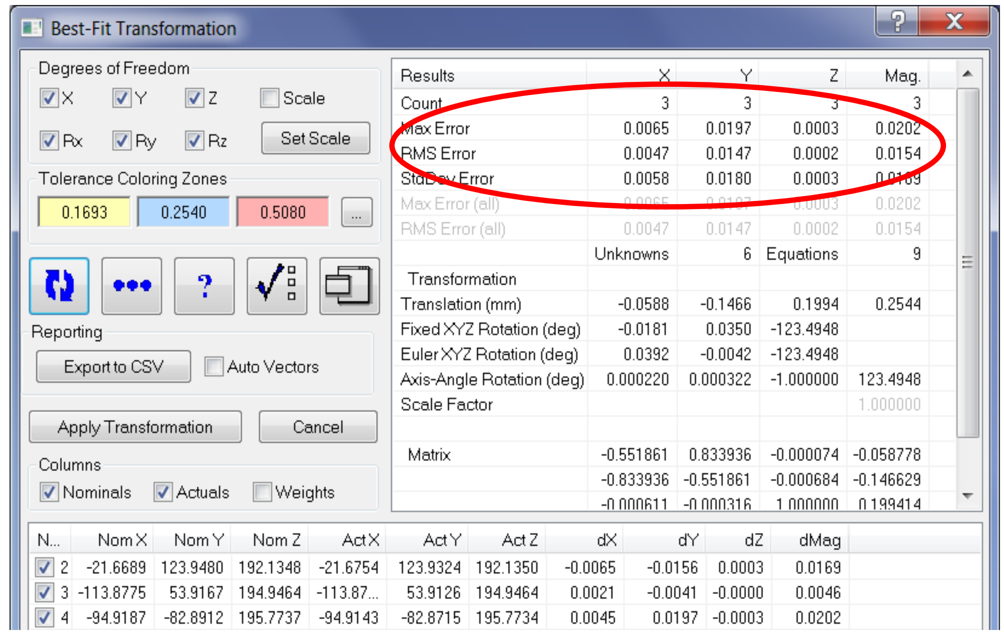




WP 6200: Assembly

Antenna Assembly





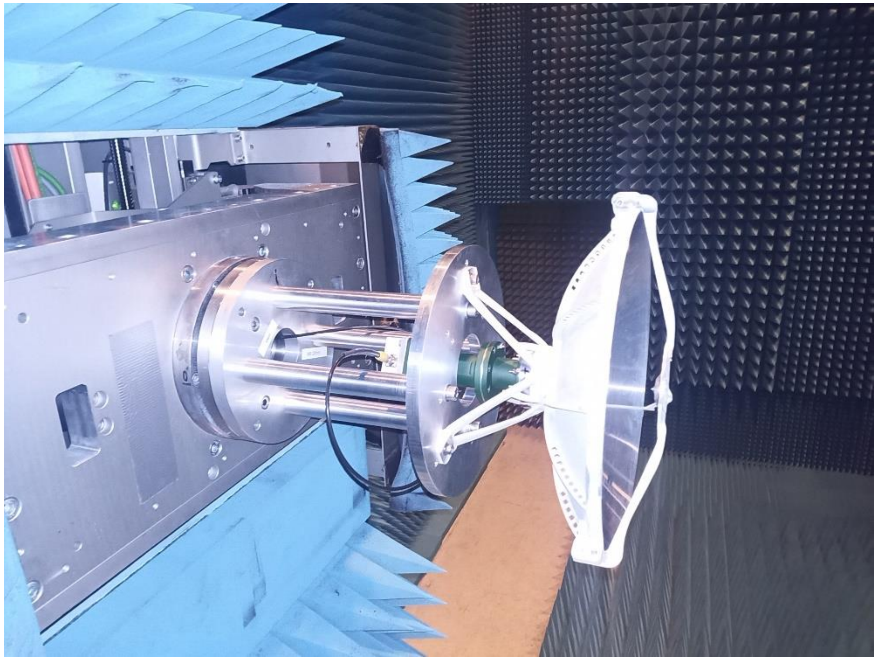
WP 6200: Deviations from Test Plan

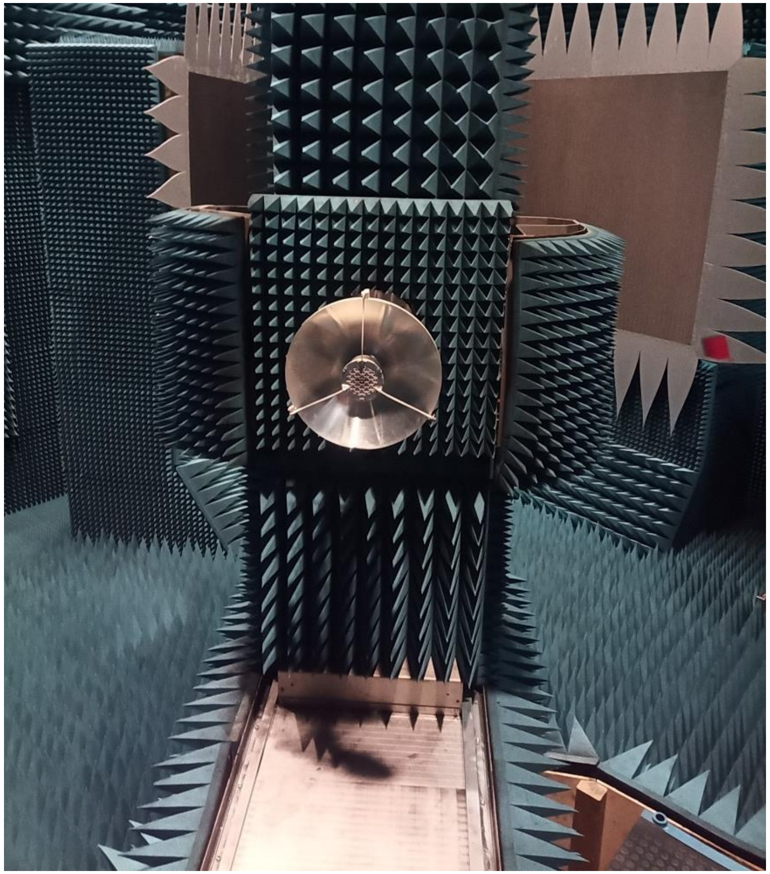
TVAC test:

Planned at AAC, replaced by Bräuninger Engineering due to non-availablity of test facility

→ Temperature range changed from ± 150°C to ± 120°C

WP 6200: RF Test Antenna





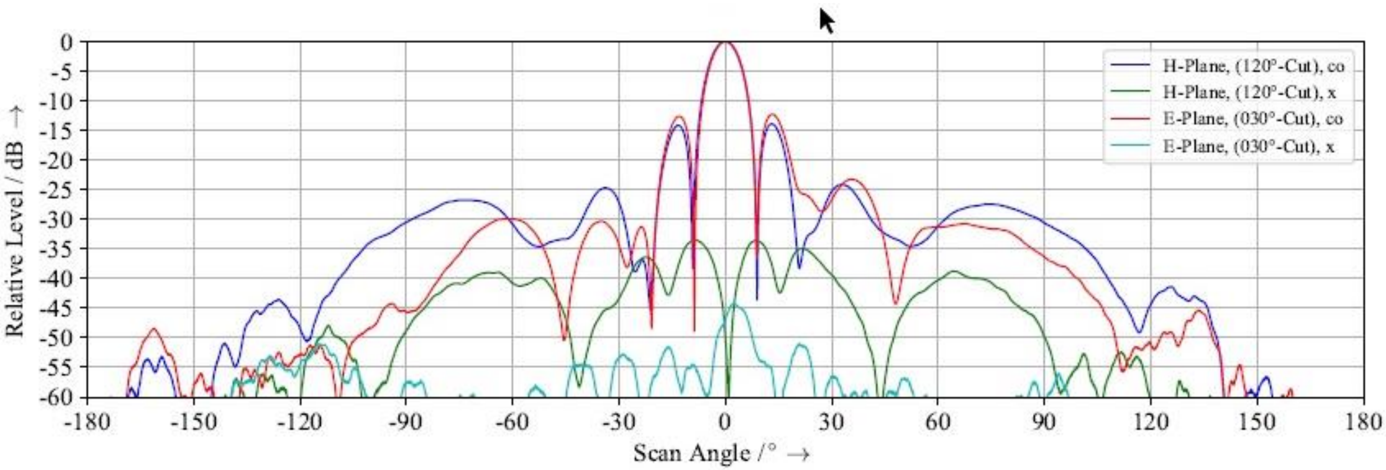
Return loss (8 – 8.4GHz): below 22dB

Antenna Gain: slidly below 26 dBi (required > 26 dBi) with margin of 2.5dB (required 3dB)

Pattern measurements: see next slide (for 8.025GHz as an example)

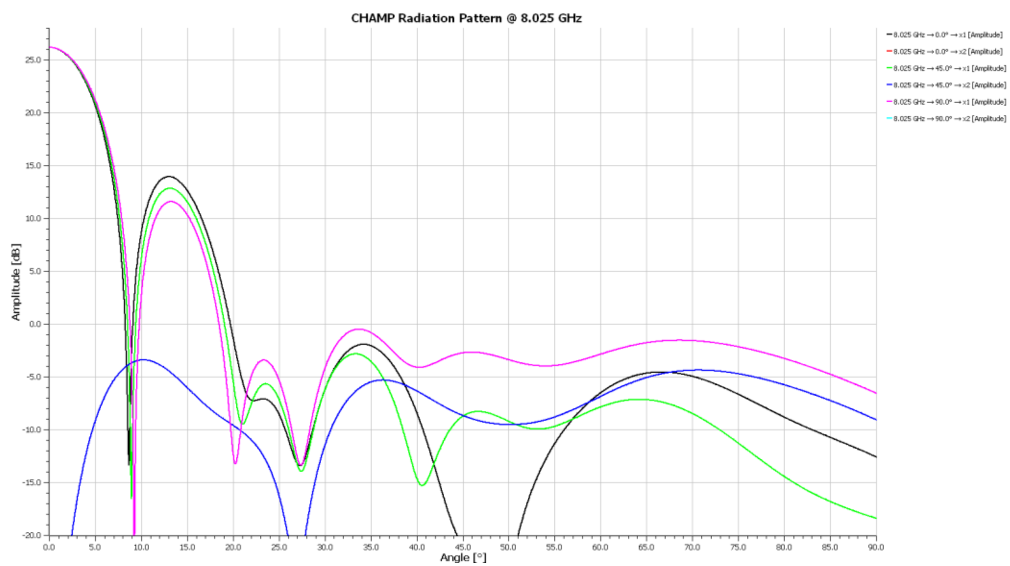
→ Good quality of the AM hardware

WP 6200: RF Test Antenna – Pattern Measurement

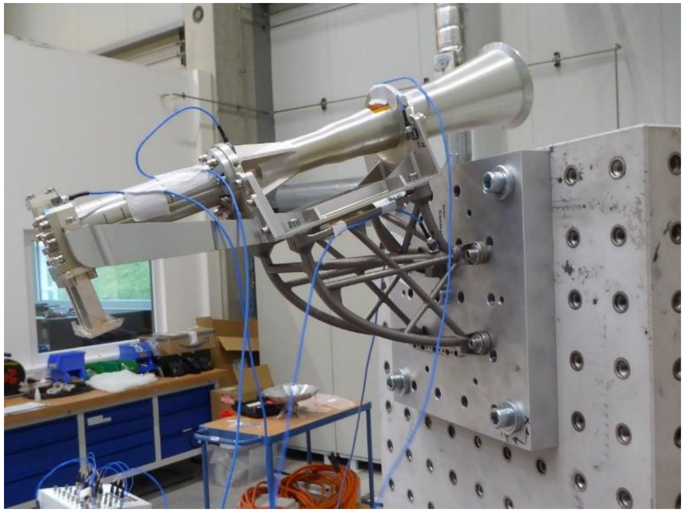


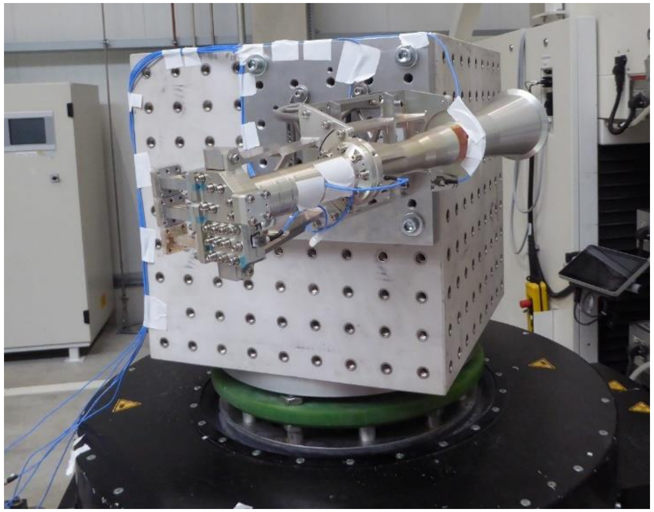
Main outcome:

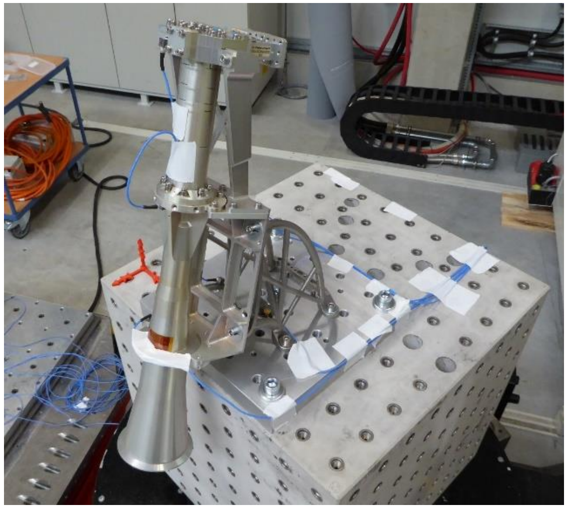
- measured 3 dB beamwidth corresponds well with the theoretical one
- measured first sidelobe level is higher than theoretical one
- measured cross-polar level is very low



WP 6200: Vibration Test – Feed Tower







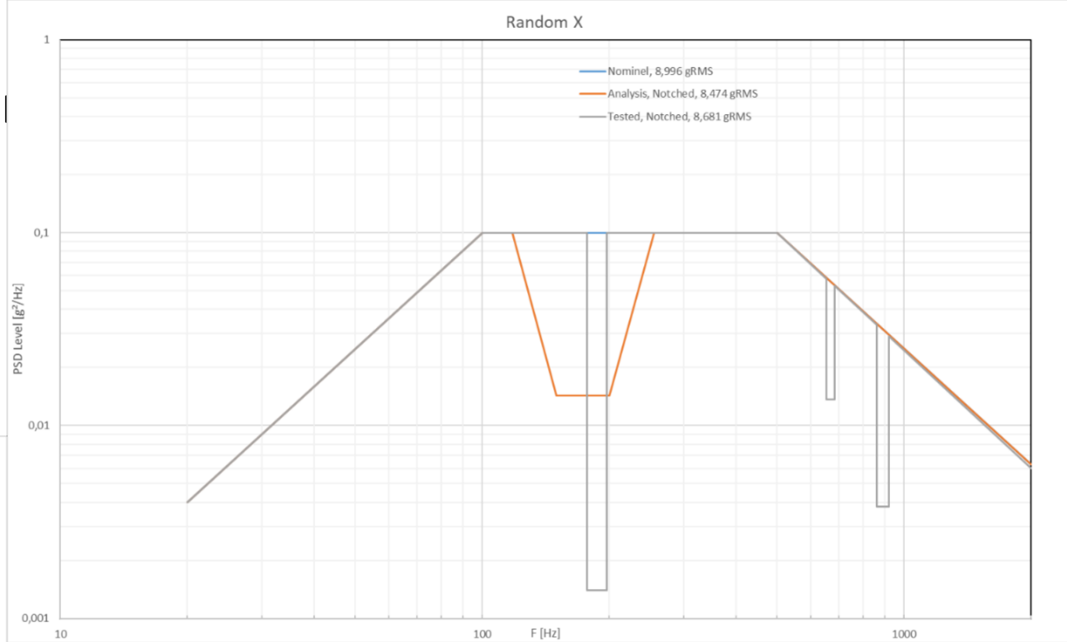
X Direction **Y Direction** **Z Direction**

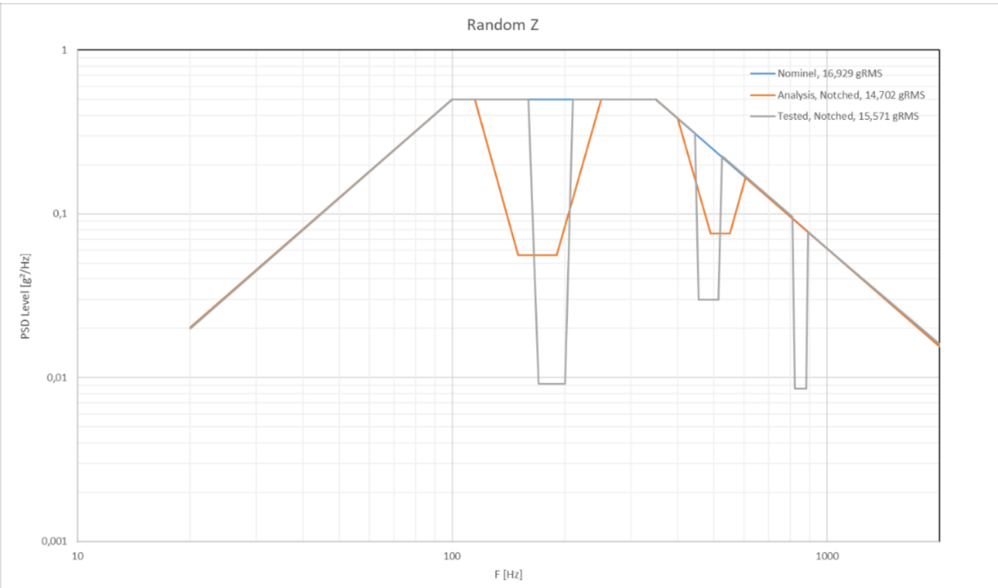
First eigenmodes:

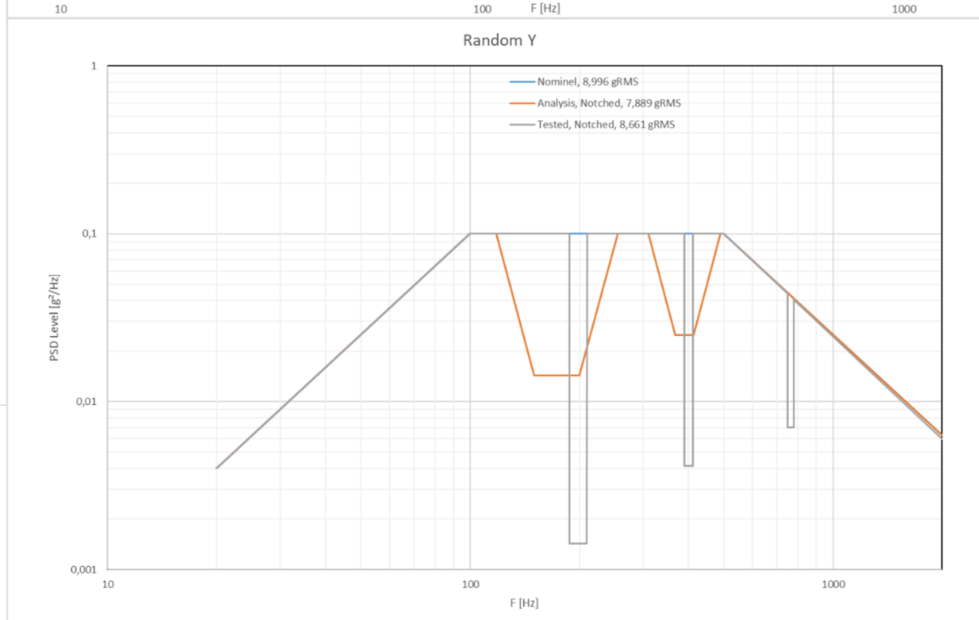
	X	Y	Z
Test	**X: 187.25 Hz**	**Y: 198.55 Hz**	**Z: 185.07 Hz**
FE:	162.9 Hz	160.0 Hz	162.9 Hz

- → **Feed Assembly survived vibration test without any damages**
- → **Interfaces shown no deviations in position**
- → **Shifts in eigenfrequency < 5%; shift in amplitudes > 20% → detailed inspection has shown no damages**

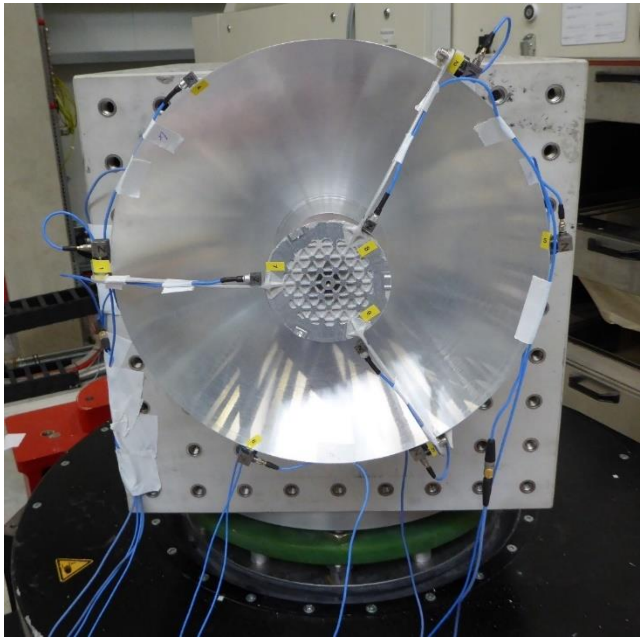
WP 6200: Vibration Test – Feed Tower



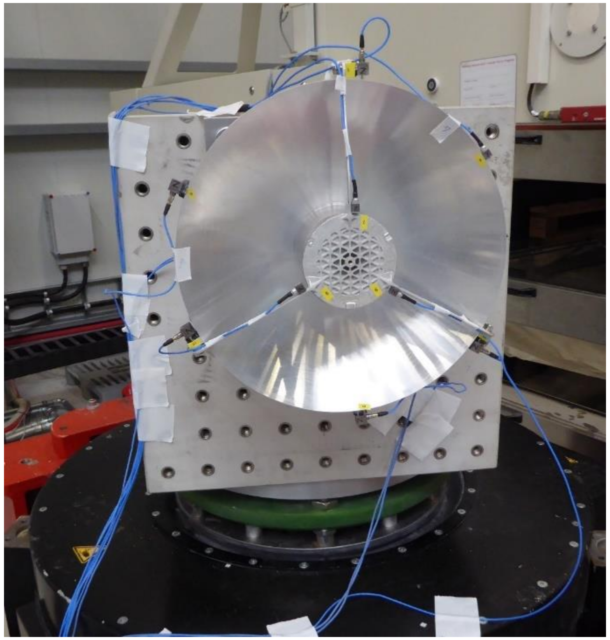




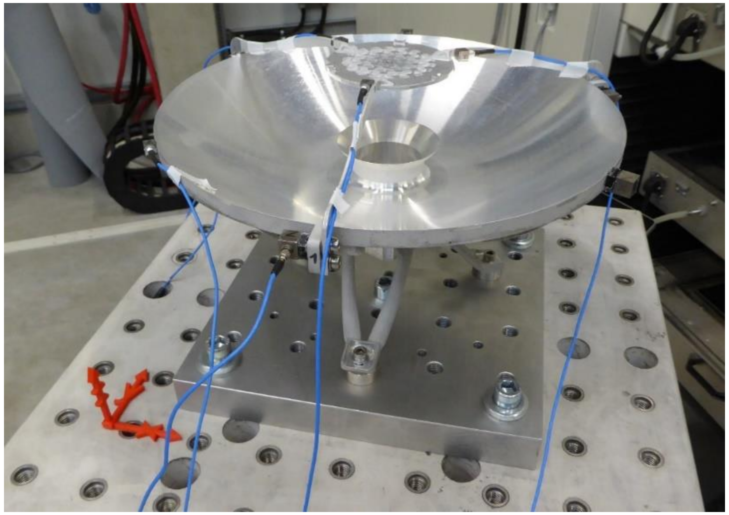
WP 6200: Vibration Test – Antenna



X Direction



Y Direction



Z Direction

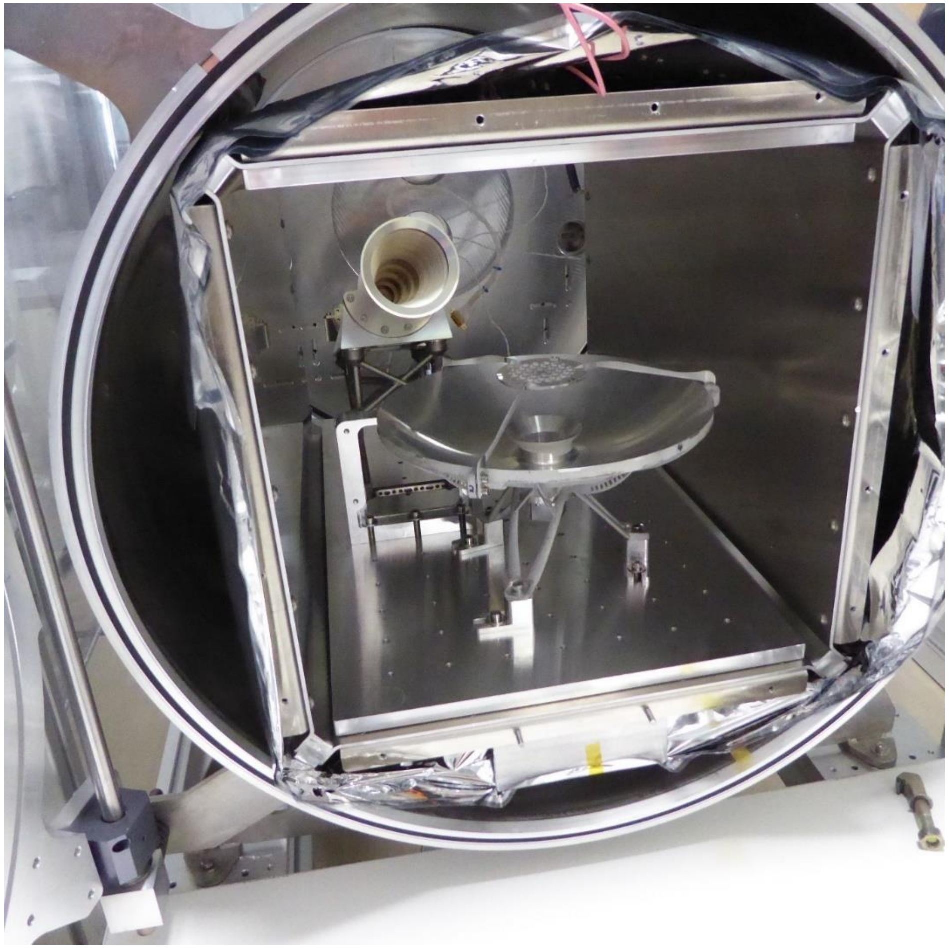
First eigenmodes:

X:	**148.11 Hz**	**Y: 148.85 Hz**	**Z: 174.53**
FE:	151.92 Hz	151.98 Hz	166.64 Hz

→ **Antenna survived vibration test without any damages**

→ **Shifts in eigenfrequency < 5%; shift in amplitudes > 20% → detailed inspection has shown no damages**

WP 6200: TVAC Test



Temperature range: +120° C to -120° C with +/-5° K
Temperature cycles: 10
Atmosphere: Vacuum

→ No damages or deformations on hardware detected
→ No slipping of interfaces at Feed Assembly and Antenna

8. Conclusion and Next Steps

Conclusion

Conclusion:

- All tasks successfully performed
- Material database for Scalmalloy defined
- Material database for Ti6Al4V extended
- Demonstrators tested successfully in vibration and TVAC test
- AM process qualified acc. To ECSS-Q-ST-70-80C:
  For Scalmalloy TRL 4 increased to TRL 6 for flight hardware
  For Ti6Al4V TRL 4 can be increased to TRL 6 for flight hardware just with acceptance by ESA (material change on AM machine at FHG)

Item	Property	Relative difference between AM and CM	Comment
Feed tower	Mass	-27%	Mass reduction achieved on the AM item at comparable eigenfrequency and margin of safety and at improved thermo-elastic stability
	Manufacturing cost	-25%	The costs are compared taking into account the fully finished items, including the final machining for the AM parts
	Delivery time	-50%	Delivery times are compared taking into account raw material procurement
X-band Antenna	Mass	-20%	Mass reduction achieved on the AM item at comparable eigenfrequency and margin of safety
	Manufacturing cost	-36%	The costs are compared taking into account the fully finished items, including the final machining for the AM parts
	Delivery time	-50%	Delivery times are compared taking into account raw material procurement

Next Steps:

- In Orbit Verification of an antenna made using the AM technology to elevate TRL level
- Increase the number of qualified AM suppliers to reduce dependency on a single provider

Thank you for your attention!

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