

Markers
Supporting
Navigation

MSN
Development &
Qualification

Ref.: MSN.PRE.ADM.125

Issue: 1.0

19 October 2023

Clean Space Industry Days, ESTEC



AGENDA

1. INTRODUCTION

2. MARKERS DESIGN

3. COATINGS QUALIFICATION RESULTS

4. LRR AGEING TEST RESULTS

5. EQUIPMENT QUALIFICATION RESULTS

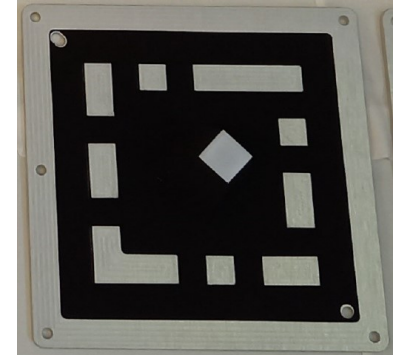
6. 2D MARKER CONTRAST MEASUREMENT

7. SUMMARY

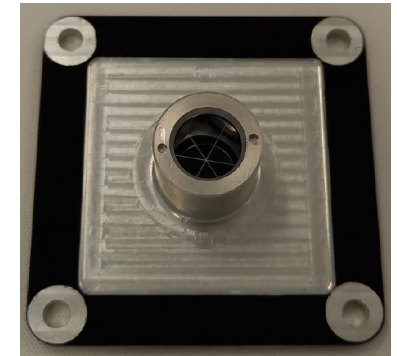


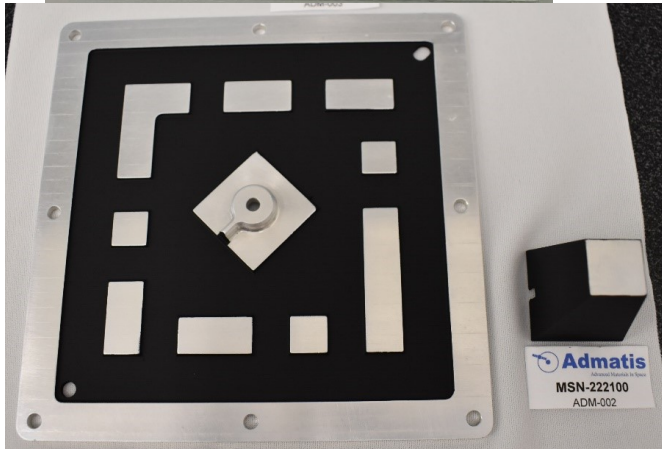
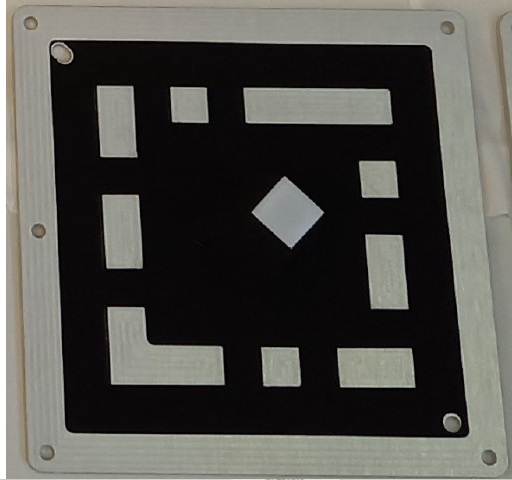
- MSN is part of **Active Debris Removal** through through ESA Clean Space initiative.
- Rendezvous and capture operations can be supported by the use of rendezvous markers, installed on the target spacecraft, as a passive solution to improve the target recognition and pose estimation.
- From far to close rendezvous (50-5m), planar distributed 2D markers can be used
- For capture (below 5m), a single 3D marker is required to perform pose estimation.
- Accurate determination of both the spin rate and spin axis are important.
- Distributed LRRs allow for accurately determining the satellite attitude from ground, due to having unique LRR patterns on each face.
- A similar pattern can be used for 2D rendezvous markers and thus the LRR and 2D marker technology can be integrated.

3D Marker

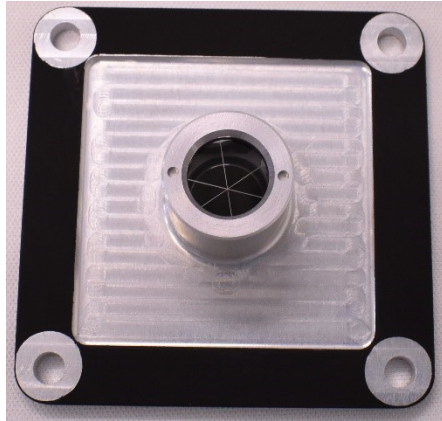
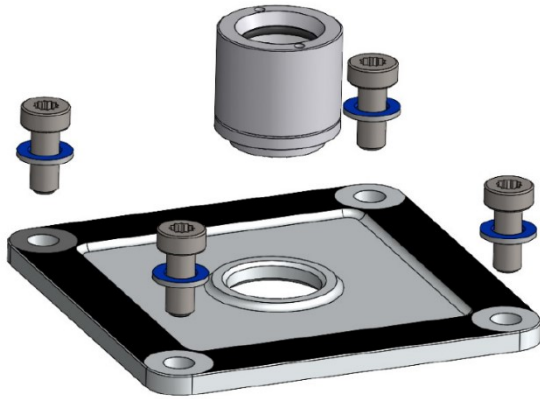


2D Marker





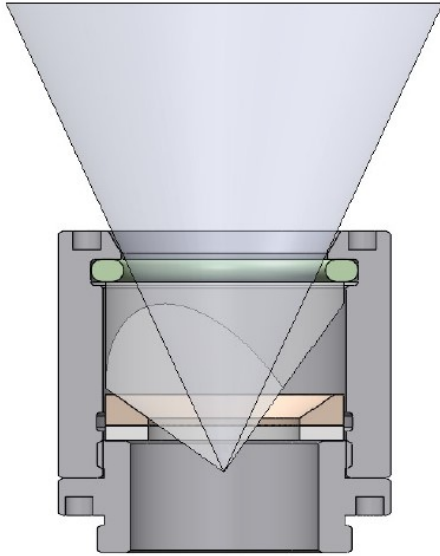
- two-piece construction of a 150×150mm EN AW6082 T6 aluminium base plate with 3mm thickness and a pyramidal element with 40mm height attached to the base plate by an MJ4×10 LN29950 Ti6Al4V screw
- bore and slot for adjustment (dowel) pins
- Alignment with Ø5mm dowel pins
- Coating: Surtec 650 + PNC
- Attachment to SC: 5pcs of MJ4×15 LN29950 Ti6Al4V screws + M4 NFL 23112 Nuflon-coated SS countersunk washers.
- Mass:0.213kg; using 20% mass margin for screws and washers: 0.25kg
- Grounding is implemented by the interface screws.
- coatings are Surtec 650 and a black paint PNC giving contrast in the VNIR and TIR spectra for detection



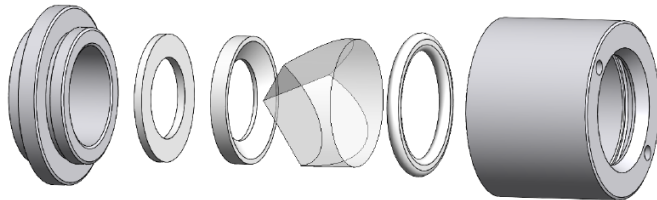
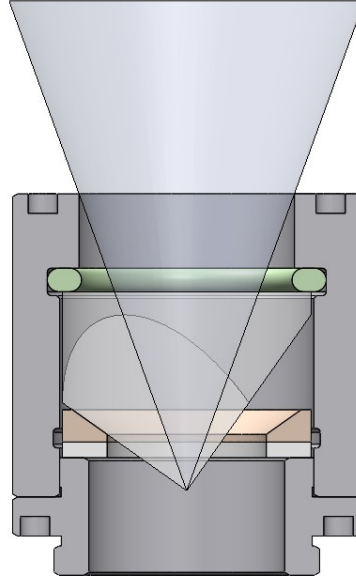
- construction of a 60×60mm baseplate EN AW6082 T6 aluminium with 3mm thickness and an LRR unit with 15.2mm height and $\varnothing 17.8$ screwed to the base plate by $\varnothing 0.535$ "-40TPI optical thread
- Coating: Surtec 650 + PNC
- Attachment to SC: 4pcs of MJ4×10 LN29950 Ti6Al4V screws + M4 NFL 23112 Nuflon-coated SS countersunk washers.
- Mass:0.035kg; using 20% mass margin for screws and washers
- Grounding is implemented by the interface screws.



QM



PT for CRISTAL

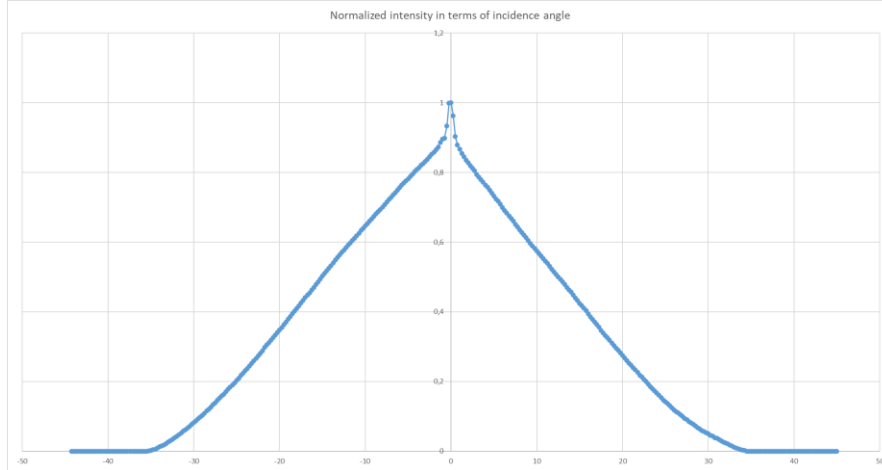


- EN AW6082 T6 aluminium housing
- groove at the upper part to hold the FKM O-ring that gives an elastic support for the CCR.
- CCR is a $\varnothing 12.7\text{mm}$ Aluminum Coated, Fused Silica Corner Cube manufactured and supplied by Edmund Optics
- CCR is supported by a PEEK supporting ring and PTFE adjustment shim is placed to reduce friction.
- Parts are fixed by an EN AW6082 T6 aluminium retaining ring.
- For CRISTAL, the height of the Tube is increased from 13.2 mm to 15.5 mm to make reflected beam intensity to zero at incidence angles higher than ± 25 deg.



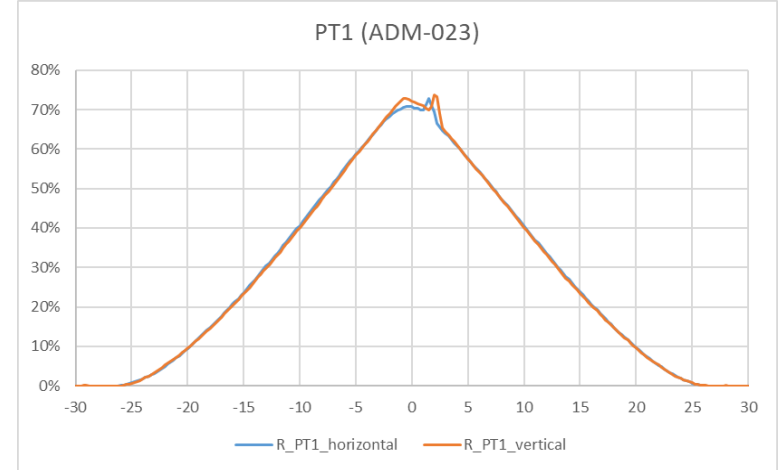
FOV measurement on LRR units

QM



Reflected beam intensity is below 20% at +/- 25 deg.

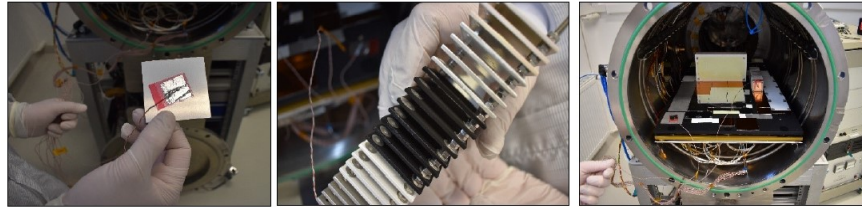
PT for CRISTAL



Reflected beam intensity is below 1% at +/- 25 deg.



TEST SEQUENCE & LEVELS: TO COVER THE 6 HPCM REQUIREMENTS



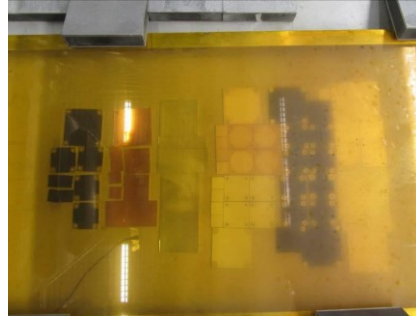
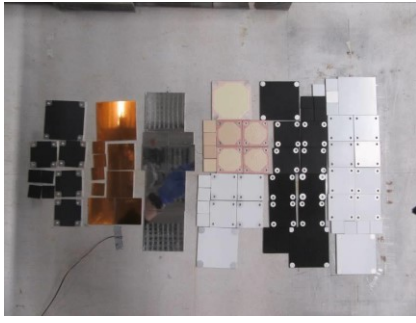
Bake out & pre-screen TVAC

Vacuum level:	min. 5E-6 mbar,
Bakeout temperature:	80°C
Duration:	minimum 72 hours,
TVAC temp. / cycles:	-60 °C / +120 °C / 8



Humidity

Humidity level:	95% RH
Temperature:	50°C
Duration:	120 hours

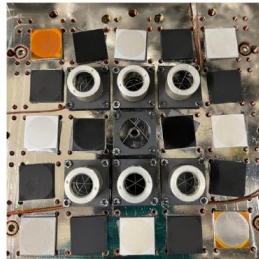
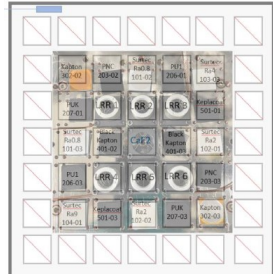
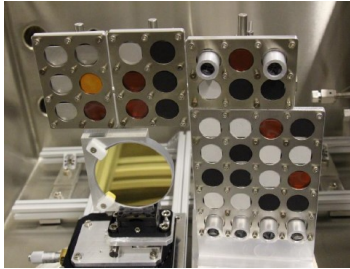
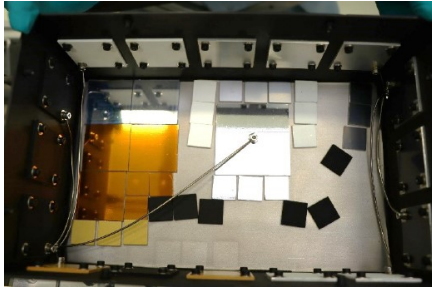


Particles (e-) irradiation

Surface dose:	180Mrad
Energy:	3MeV
Fluence (e-/cm2):	9.5E+15



TEST SEQUENCE & LEVELS: TO COVER THE 6 HPCM REQUIREMENTS



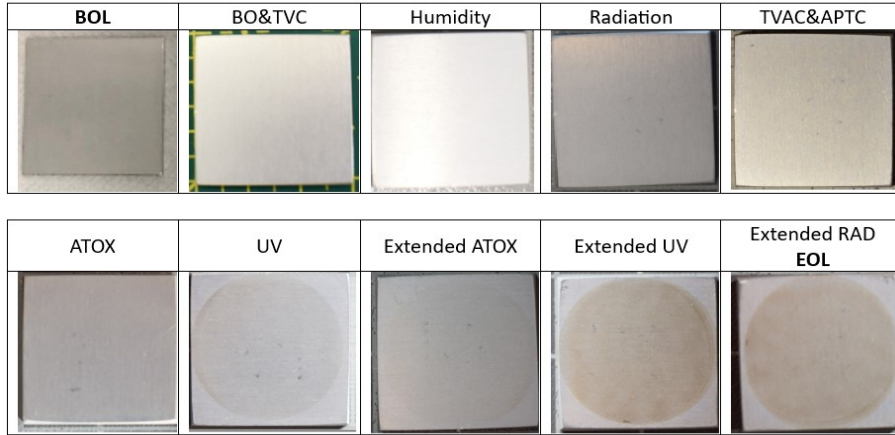
TVAC & APTC	
Pressure:	<1E-6 mbar / N2
Temperature:	-180 °C / +160 °C
Cycles:	20 + 80

ATOX	
Fluence:	2.7E21 atoms/cm2
Pressure:	<1E-6 mbar
Typical atomic oxygen (AO) energy:	5.5 eV

UV	
Dose:	7181 ESH
Pressure:	<1E-6 mbar
Acceleration factor:	4.5 SC



SURTEC 650 RTU



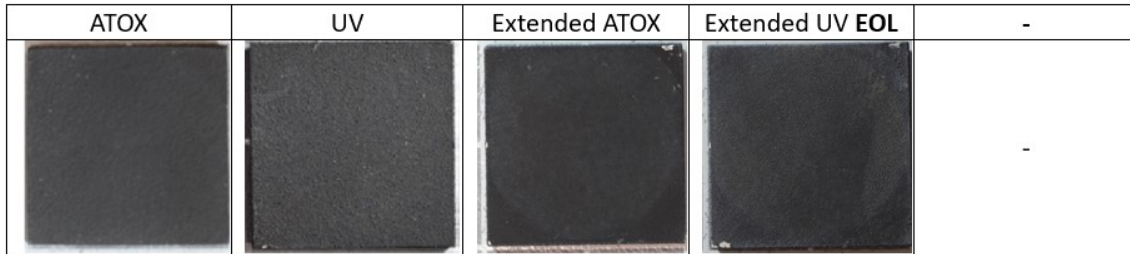
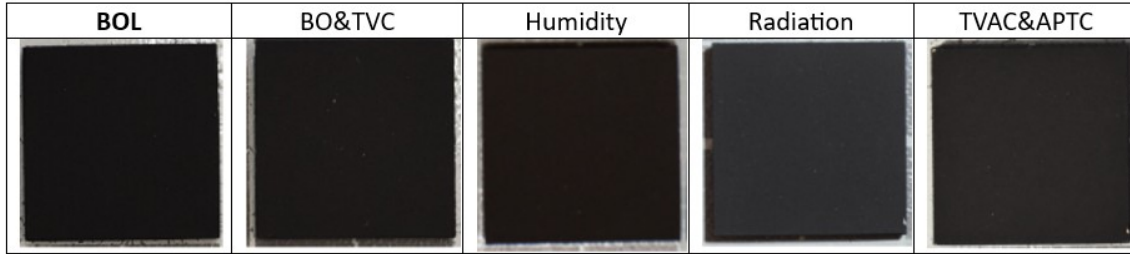
- slight darkening
- All samples passed the visual inspection and the adhesion (tape-lift) tests after each ageing tests.

Surtec 650RTU passed the aging tests successfully and therefore considered to be qualified.

TO property	BOL	After TVAC	After ATOX	After UV	After Ext. ATOX	After Ext. UV	After Ext. Rad. EOL	Δ
Solar absorptance	0.29	0.33	0.32	0.32	0.31	0.42	0.44	+0.15
Thermal emittance	0.03	0.05	0.04	0.04	0.02	0.02	0.04	+0.01



PNC



- Visual change due to aging is negligible.
- All samples passed the adhesion (tape-lift) test after each ageing tests.

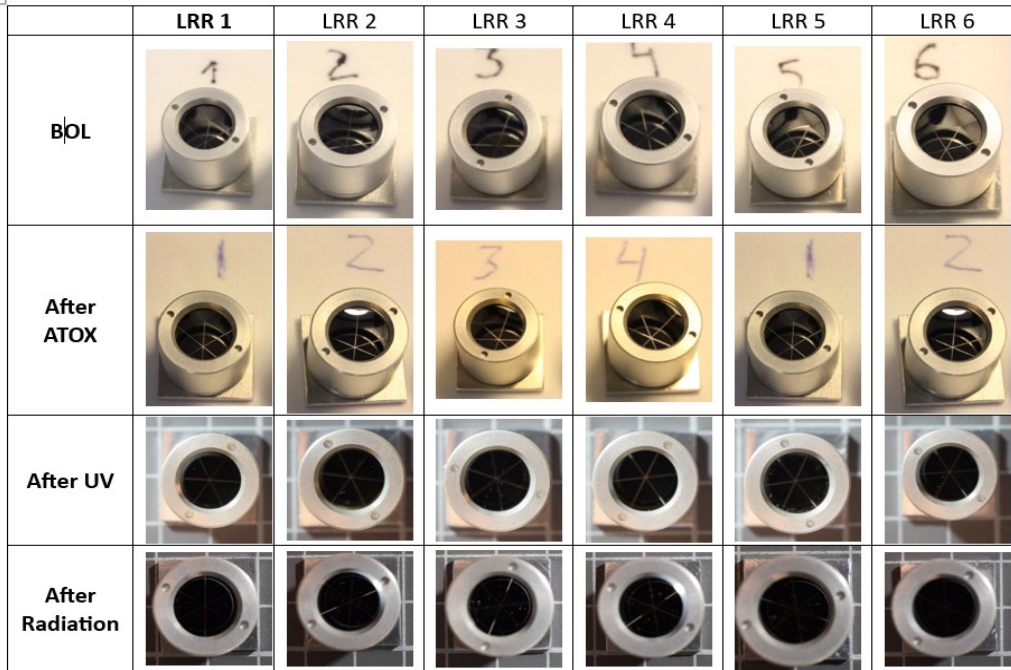
PNC coating passed the aging tests successfully and therefore considered to be qualified.

TO property	BOL	After TVAC	After ATOX	After UV	After Ext. ATOX	After Ext. UV EOL	Δ
Solar absorptance	0.97	0.97	0.97	0.97	0.97	0.97	0.00
Thermal emittance	0.93	0.90	0.92	0.95	0.96	0.96	+0.03



LRR units

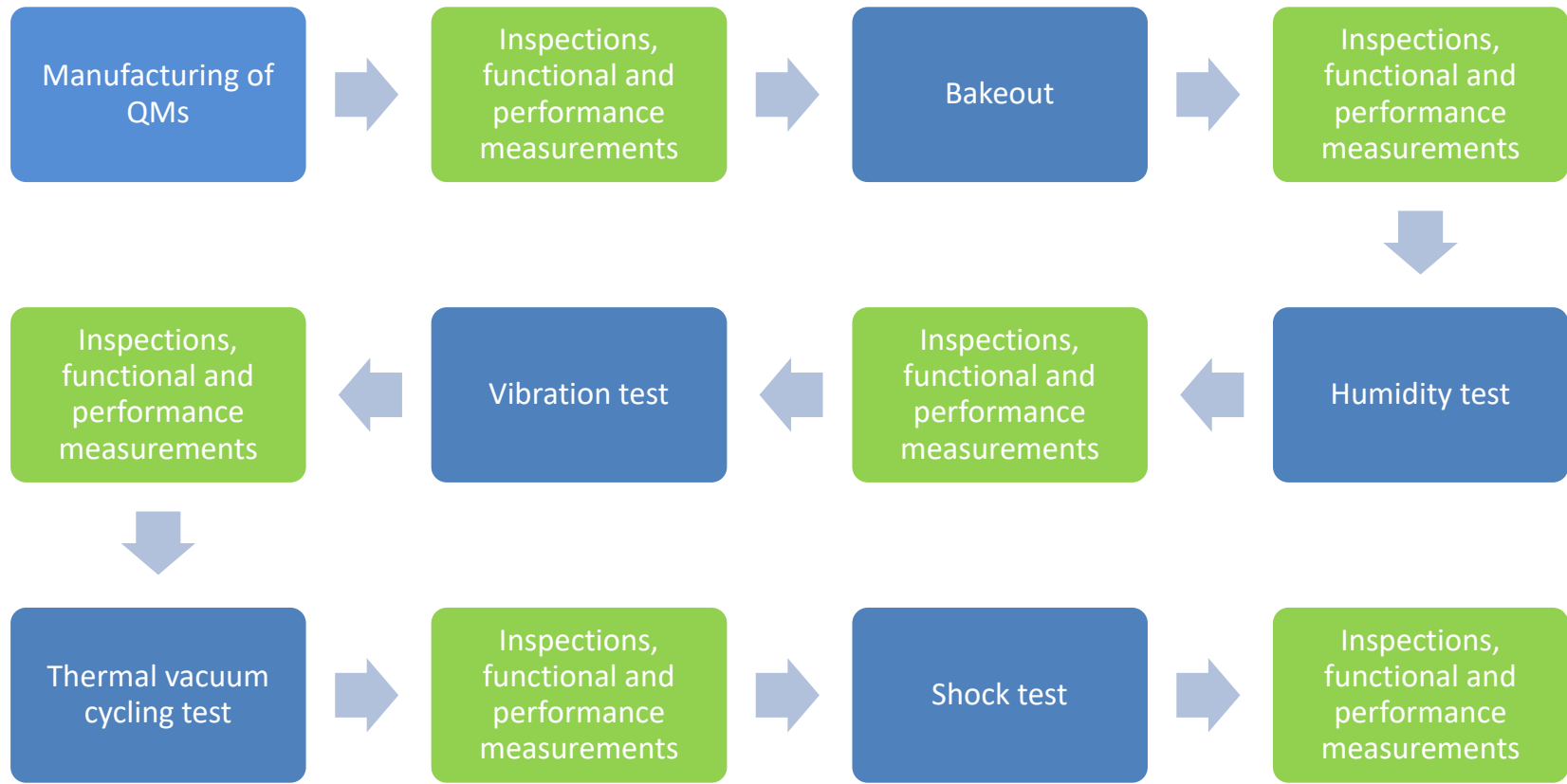
- LRR units have been subjected to the same ageing qualification tests as the coatings
- Critical functions are the optical properties (WFE, FFDP, reflectivity)



CI number		BOT		After ATOX		
LRR S/N	CCR S/N	WFE (532nm)	R(%)	WFE (633nm)	R(%)	ΔR (%)
#1	ADM-002	20.727	59.7	28.95	57.5	3.8%
#2	ADM-003	22.344	59.6	40.08	55.4	7.6%
#3	ADM-004	33.207	59.8	70.96	57.3	4.4%
#4	ADM-005	41.256	59.3	68.98	54.6	8.6%
#5	ADM-006	26.482	60.3	40.39	56.7	6.3%
#6	ADM-007	19.907	58.5	52.14	57.3	2.1%



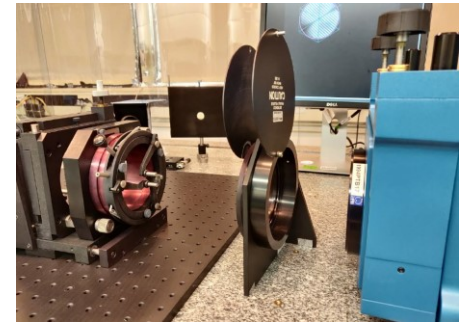
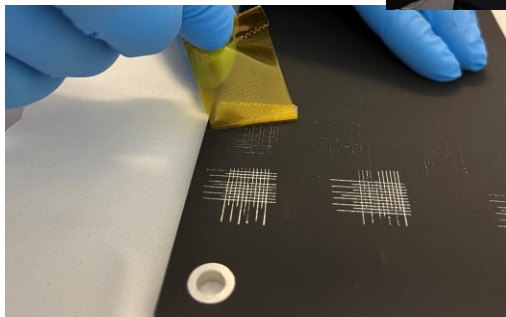
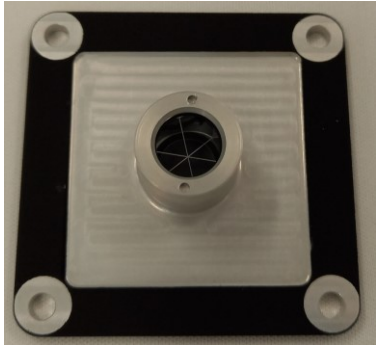
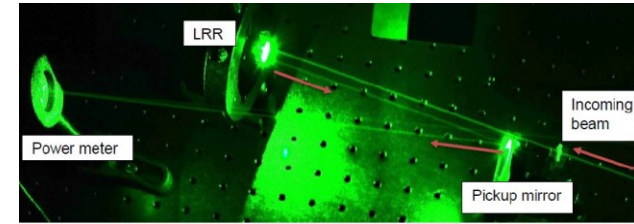
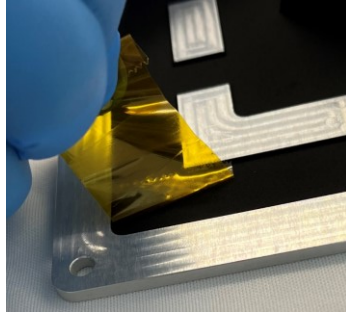
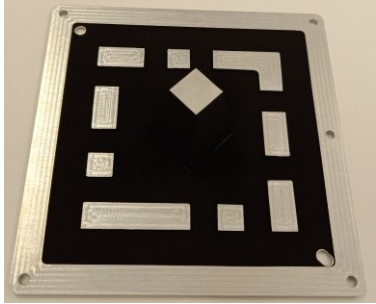
MAIT flowchart





ACCEPTANCE CRITERIA

- Visual appearance
- Adhesion
- Structural integrity
- Grounding resistance
- Optical properties of LRR (WFE, reflectance)





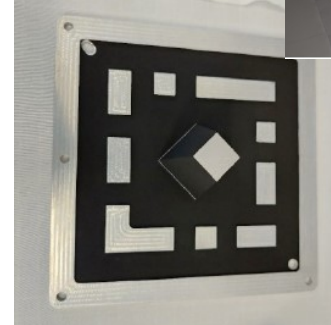
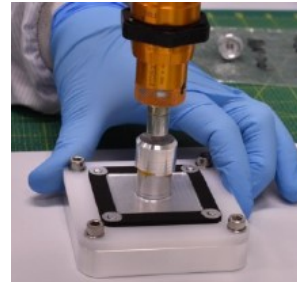
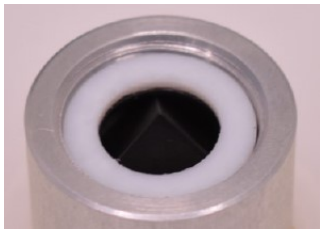
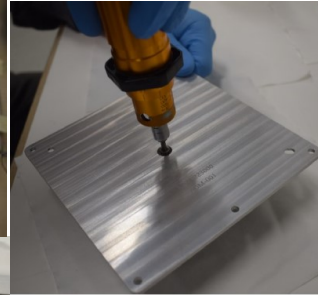
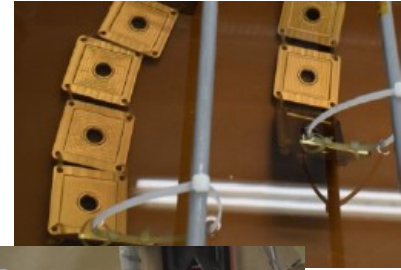
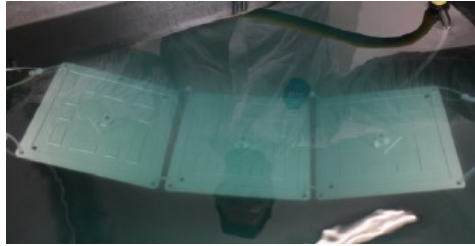
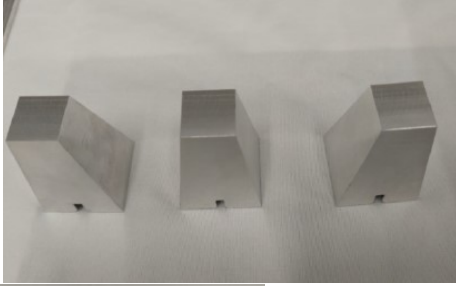
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EQUIPMENT QUALIFICATION



Admatis

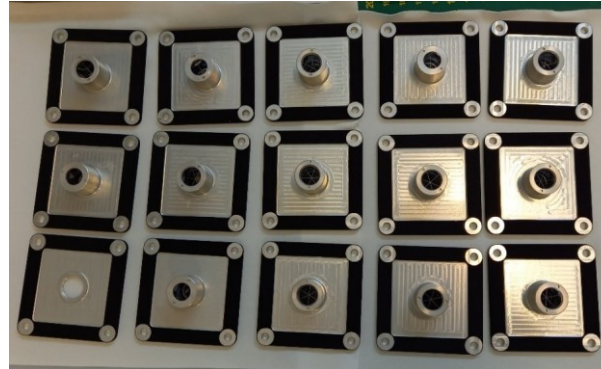
MANUFACTURING



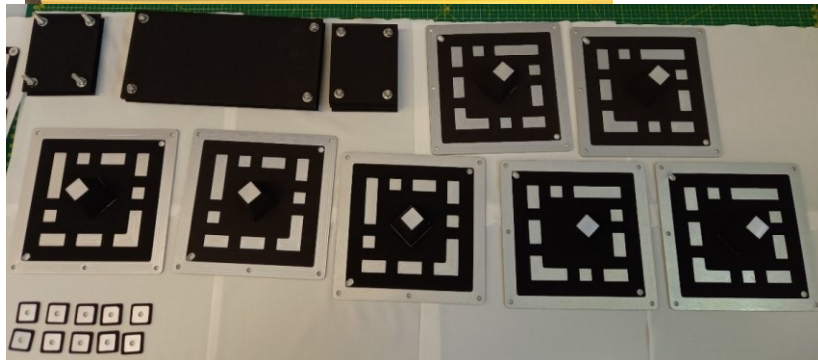


BAKEOUT

- Bakeout is performed as the final step of the manufacturing, and it is used for pre-conditioning of hardware for space use and cleanliness improvement.



Bakeout	
Vacuum level:	<5E-6 mbar,
Bakeout temperature:	80°C
Duration:	minimum 72 hours,



- All items passed the inspections and measurements.
- Cleanliness measurement result: $0.12 \times 1E-07$ g/cm².
- Bakeout of all items is considered successful.



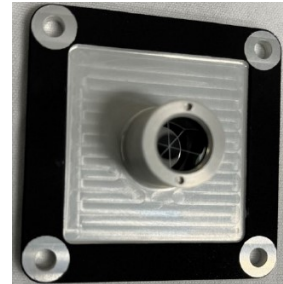
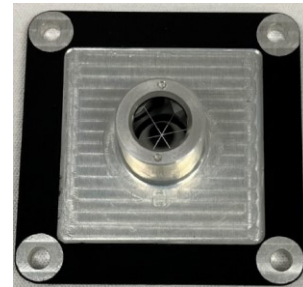
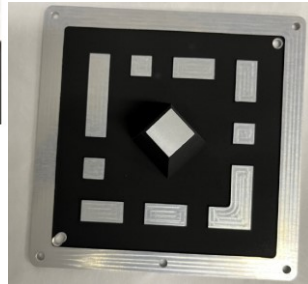
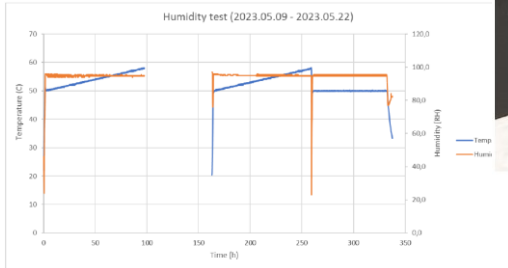
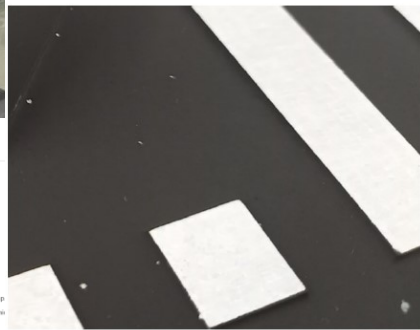
HUMIDITY (DAMP HEAT) TEST

- Humidity-, or damp heat test is a control for corrosion resistance of exposed surfaces like conversion coating and topcoats stored in Class 6 (indoor, controlled) environment.



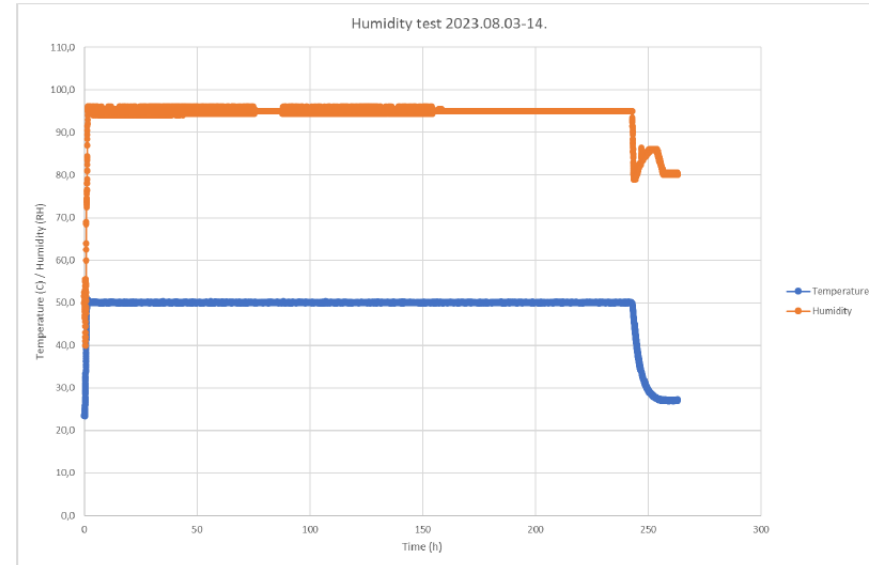
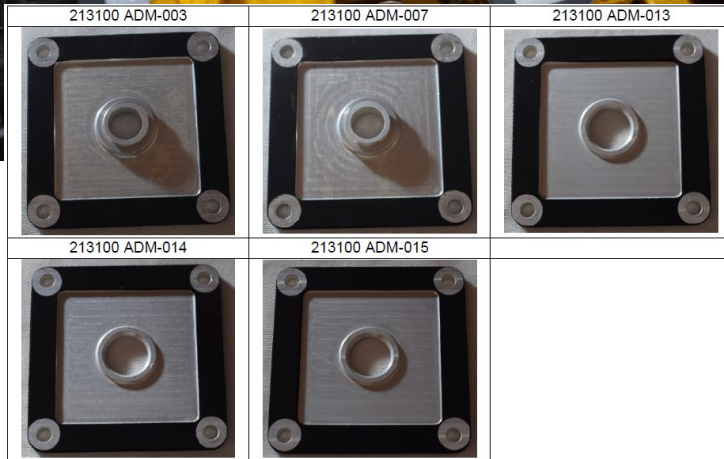
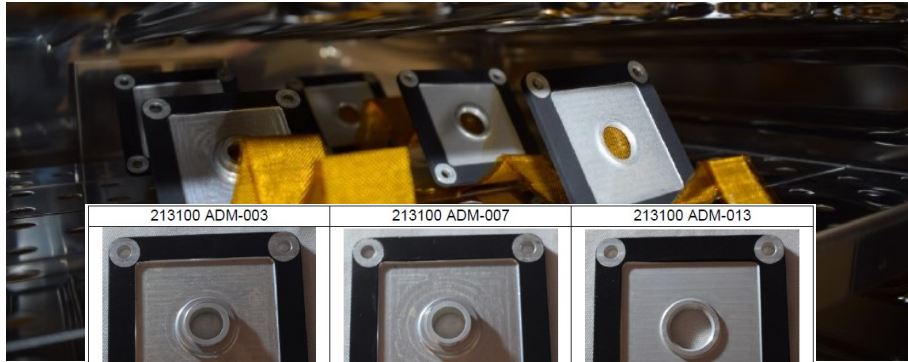
Humidity	
Humidity level:	95% RH
Temperature:	50°C
Duration:	240 hours

- unexpected power outage.
- Test articles spent 2 days under uncontrolled conditions.
- Visual failure has been observed on 3D Markers and corresponding witness plate painted with PNC after the humidity test.
- All other items have passed the visual inspection.
- All items passed the adhesion tests.





HUMIDITY (DAMP HEAT) TEST-REPEAT

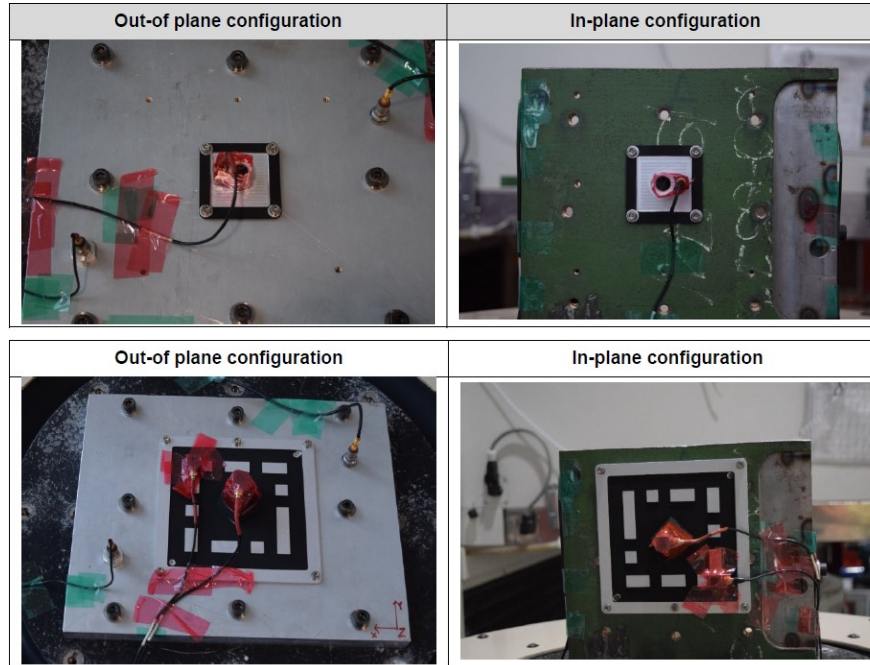


- All items passed the visual inspection and the tape-lift test.
- Based on the test results of the repeated humidity test, the unexpected test chamber failure has been found as the cause of the NC.
- Based on these results, the humidity test of QMs has been considered successful.



VIBRATION TEST

- Vibration test is performed to prove that equipment is free of workmanship defects and will be able to survive launch and on-orbit loads without loss of functionality.





VIBRATION TEST-LEVELS

Qualification level random (120s)

Out-of plane			
Frequency (Hz)	ASD (g2/Hz)	Level	gRMS
20	0.301657	+3 dB/oct	32.9
100	1.5	1.5 g2/Hz	
500	1.5	1.5 g2/Hz	
2000	0.0376783	-8 dB/oct	

In- plane			
Frequency (Hz)	ASD (g2/Hz)	Level	gRMS
20	0.103844	+ 3 dB/oct	25.4
70	0.361899	+ 12 dB/oct	
100	1.5	1.5 g2/Hz	
300	1.5	1.5 g2/Hz	
400	0.357713	-15 dB/oct	
2000	0.0719377	-3 dB/oct	

Low level sine

Frequency Search Spectrum			
Frequency (Hz)	Amplitude (g)	Speed (Oct/min)	Direction
5 to 2000	0.2	2	One sweep up

Qualification sine (2oct/min)

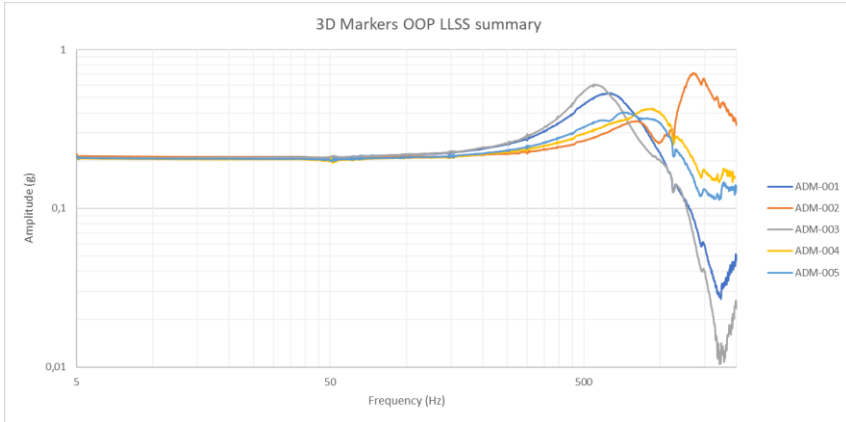
All axis	
Frequency (Hz)	Level
5-30	±22.5mm
30-125	30g

Req.

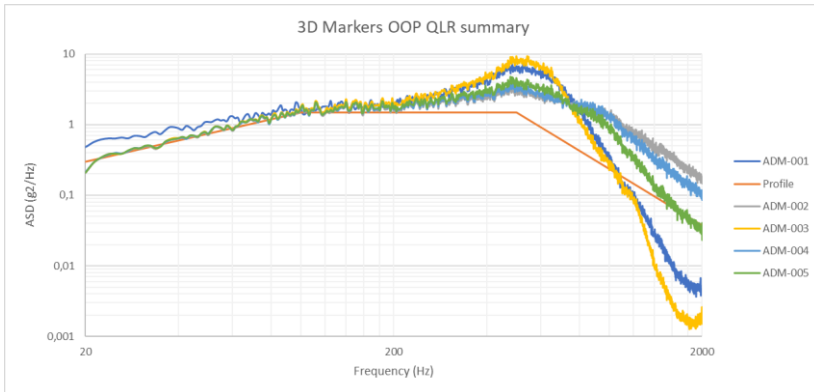
All axis	
Frequency (Hz)	Level
5-20	±22.5mm
20-125	30g



VIBRATION TEST-3D Marker results



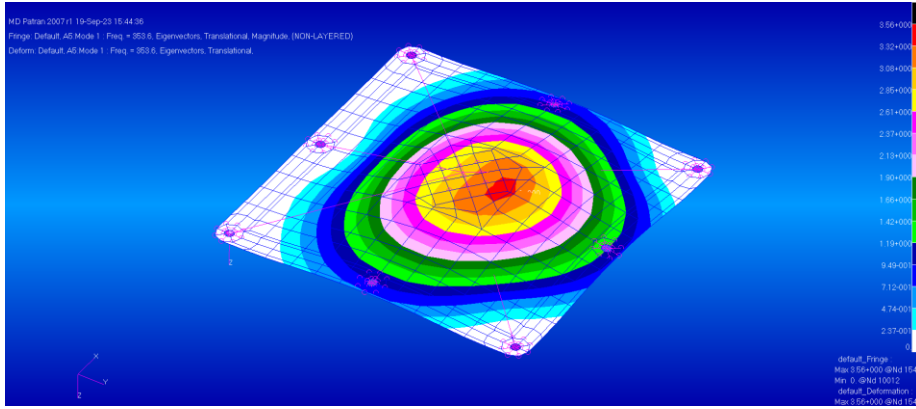
CI number	First frequencies (Hz) – Low level sine sweep		
	Z	X	Y
223000 ADM-001	641	595	599
223000 ADM-002	814	594	592
223000 ADM-003	568	606	599
223000 ADM-004	937	597	599
223000 ADM-005	726	597	599



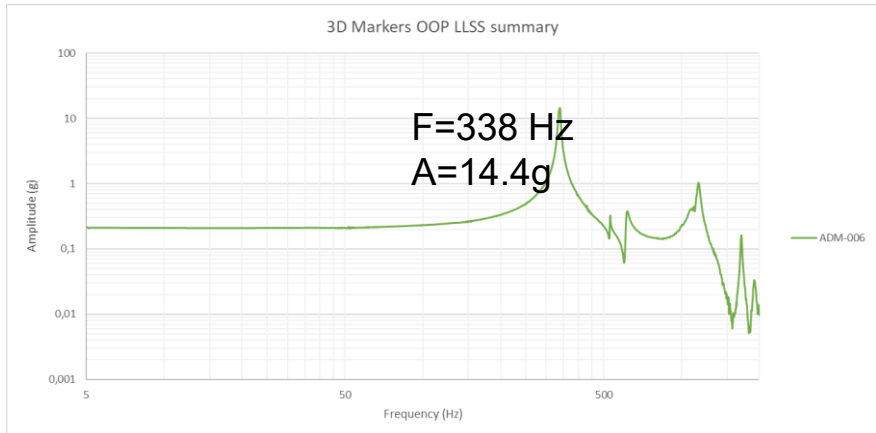
CI number	First frequencies (Hz) – Qualification level random		
	Z	X	Y
223000 ADM-001	541	588	588
223000 ADM-002	N/D	580	580
223000 ADM-003	541	588	588
223000 ADM-004	N/D	588	588
223000 ADM-005	N/D	588	588



VIBRATION TEST-3D Marker results-OOP LLSS-thermal washers configuration



- Analysis resulted 354Hz which is in line with the 338 Hz measured frequency.
- Requirement for secondary structure is 140 Hz for the first main mode, which is well above the requirement.





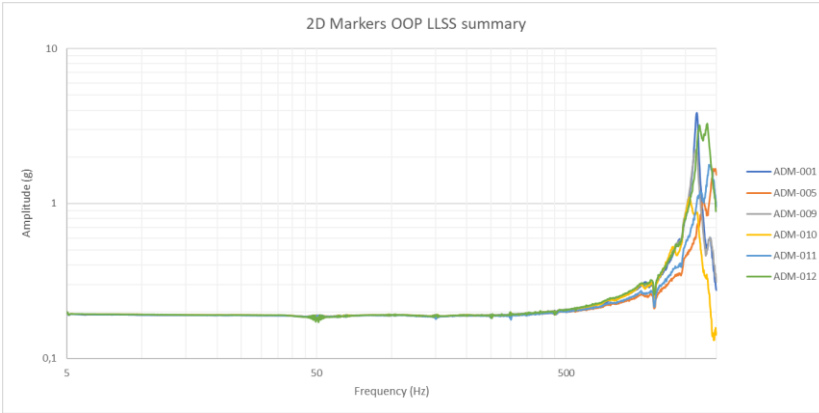
MSN

EQUIPMENT QUALIFICATION

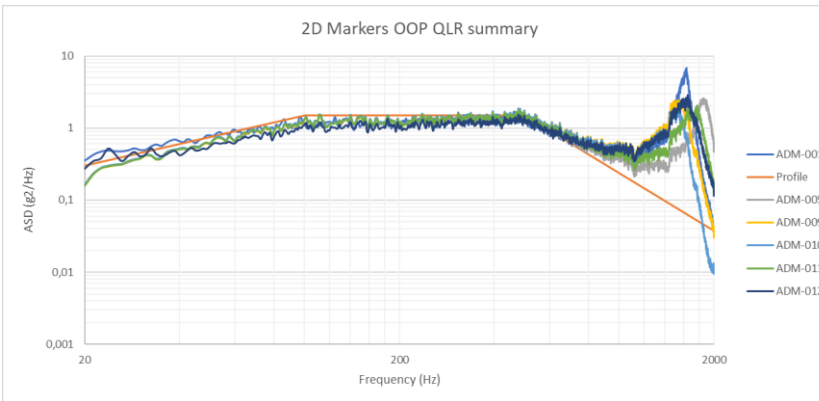


Admatis

VIBRATION TEST-2D Marker results



CI number	First frequencies (Hz) - Low level sine sweep		
	Z	X	Y
213000 ADM-001	1 668	604	604
213000 ADM-005	1 977	604	604
213000 ADM-009	1 658	604	-
213000 ADM-010	1 559	604	-
213000 ADM-011	1 864	604	-
213000 ADM-012 (THW)	1 708	602	-



CI number	First frequencies (Hz) - Qualification level random		
	Z	X	Y
213000 ADM-001	1 641	595	594
213000 ADM-005	1 851	594	594
213000 ADM-009	1 540	594	-
213000 ADM-010	1 485	594	-
213000 ADM-011	1 770	594	-
213000 ADM-012 (THW)	1 653	594	-



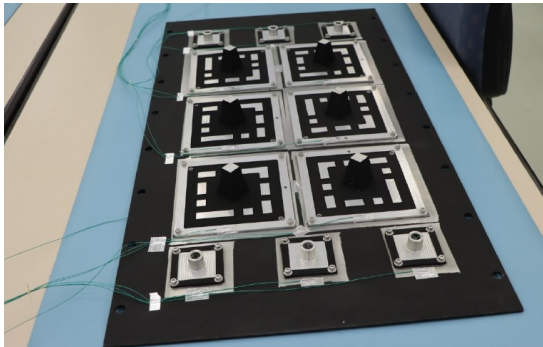
VIBRATION TEST-SUMMARY

- There was no sign of cracks, deformation, disintegration during and after the vibration test on the test articles.
- There was no sign of cracks, deformation, disintegration during and after the vibration test on the LRR units.
- All items withstood the QL loads without degradation.
- No nonconformances have been revealed as a result of the vibration test.
- 3D measurement results after the vibration test showed no major deviations - significantly out of tolerance- compared to ones recorded before the vibration test.
- All items passed the grounding measurement after the vibration test.
- Vibration test of the 2D Markers Qualification Models in the configuration in terms of random and sine test is considered successful.



THERMAL VACUUM CYCLING TEST

- Thermal vacuum cycling test objective is to qualify the hardware in terms of on-orbit thermal conditions.



The requirement for the cold temperature of $T=-180^{\circ}\text{C}$ was not met during the test. The minimum temperature reached during the first cold cycle on the TRP (average of all test specimens) was $T=-175^{\circ}\text{C}$ which required a dwell time of 26.5 hours.

Decision has been made to reduce the cold cycle temperature requirement to $T=-170^{\circ}\text{C}$.

- Temp. Range is **$-170^{\circ}\text{C} / +160^{\circ}\text{C}$**
- $P=5.5\text{E}-06$ mbar
- 8 cycles

- All items passed the inspections & measurements
- No nonconformances have been revealed as a result of the thermal vacuum cycling test
- Based on these results, the thermal vacuum cycling qualification test of QMs has been considered successful²⁵

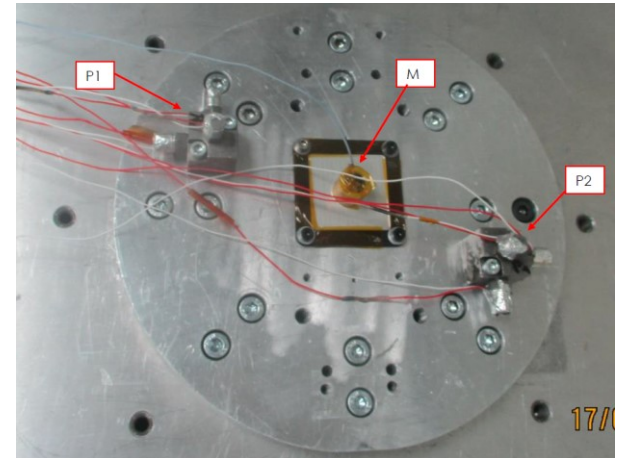


SHOCK TEST

Shock test is performed to qualify the hardware against mechanical environmental loads during the launch phase.



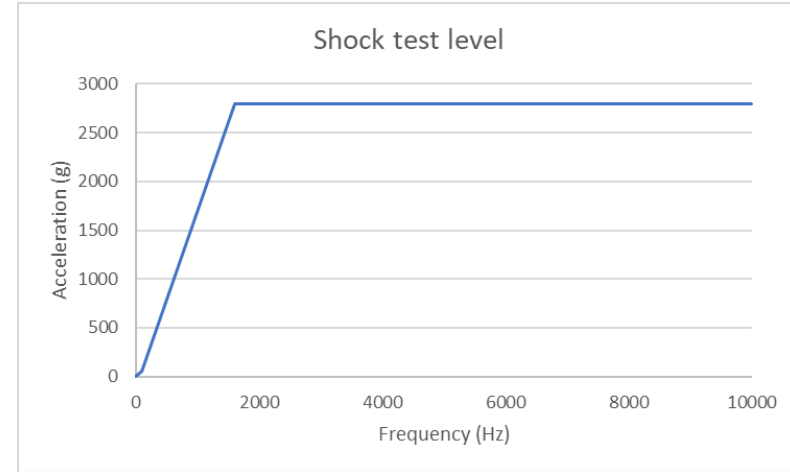
- Shock levels are controlled by two tri-axial accelerometers (P1 and P2)
- Measurement accelerometer (M) is located on the HW





SHOCK TEST-levels

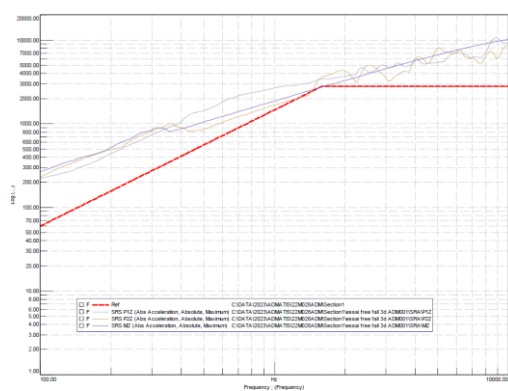
STANDARD	Handbook ECSS-E-HB-23-25A		
FREQUENCY (Hz)	100	1600	10000
ACCELERATION (g)	60	2800	2800
AXIS	X, Y and Z		
SAMPLING RATE	204,8 kHz		
DAMPING RATE	Q =10 (5%)		
SRS ANALYSIS	1/24 of Octave		
NUMBER OF SHOCK	1 per axis		



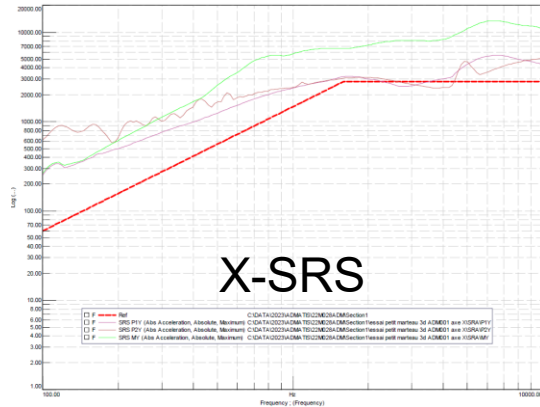
The profile is the same for both benches. Z axis is performed on free fall test bench, X and Y axes are performed on pendulum hammer test bench.



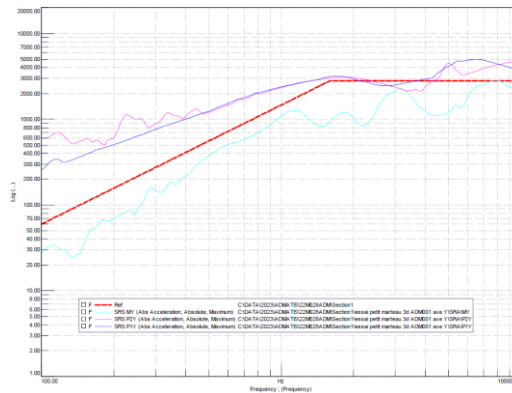
SHOCK TEST RESULTS-3D Marker



Z-SRS

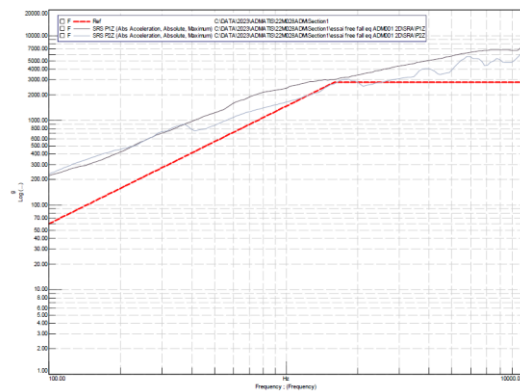


X-SRS

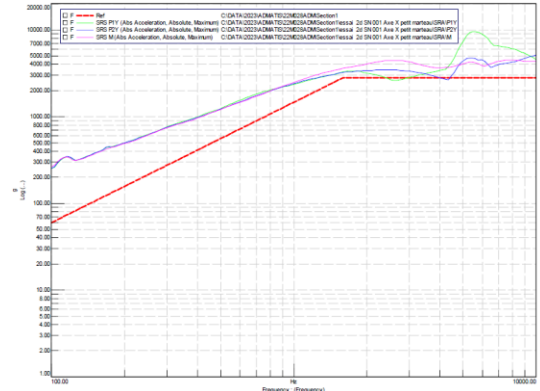


Y-SRS

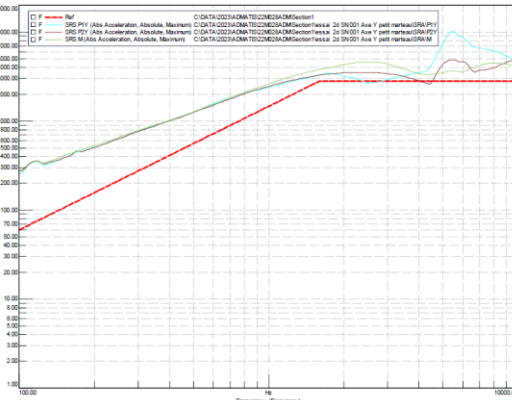
SHOCK TEST RESULTS-2D Marker



Z-SRS



X-SRS



Y-SRS

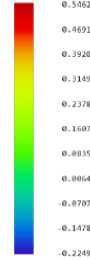
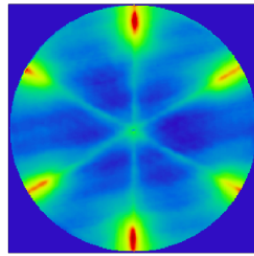
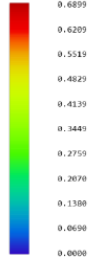
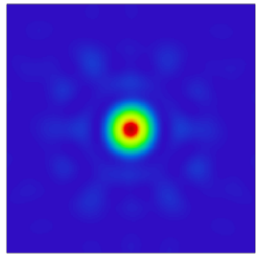


SHOCK TEST RESULTS

- There was no sign of cracks, deformation, disintegration during and after the vibration test on the test articles.
- There was no sign of cracks, deformation, disintegration during and after the vibration test on the LRR units.
- Dimension check showed minor deviation (ADM-012): The true position of the tube is out of tolerance with 0.0311 mm (tolerance is 0.1 mm).
- All items withstood the QL loads without degradation
- All items passed the grounding measurement after the shock test.
- All items passed the torque check.
- Based on these results, the shock test of QMs has been considered successful.

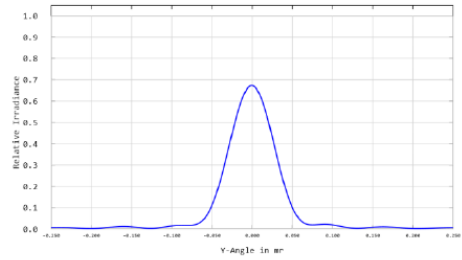


Optical measurements-2D Markers



WFE requirement is 0.1 λ .
EOT measurements show that this requirement is met.

Polychromatic FFT PSF		Wavefront Function	
2021_04_06 0.6228 μm at 0.0000 (deg) Side is 0.50 m. Surface: Image Reference Coordinates: 0.0000E+00, 0.0000E+00	Gabor Erdei, BME AFT Zemax OpticStudio retro3.zmx configuration 1 of 1	2021_04_06 0.6228 μm at 0.0000 (deg) Peak to valley = 0.7711 waves, RMS = 0.1173 waves. Surface: Image Exit Pupil Diameter: 1.1000E+01 Millimeters	Gabor Erdei, BME AFT Zemax OpticStudio retro3.zmx configuration 1 of 1



2021_04_06 Field : 0.0000, 0.0000 (deg) Wavelength: Polychromatic Lin Y Section, Center Col.	Gabor Erdei, BME AFT Zemax OpticStudio retro3.zmx configuration 1 of 1
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CI number	BOL			EOT		
	WFE P-V value (λ)	WFE RMS value (λ)	Relative irradiance at peak	WFE P-V value (λ)	WFE RMS value (λ)	Relative irradiance at peak
ADM-001	0.7711	0.1173	0.68	0.5157	0.0780	0.80
ADM-007	Subject to pre-shock test			0.6956	0.0805	0.80
ADM-009	1.0088	0.1129	0.69	0.6053	0.0739	0.82
ADM-012	0.3238	0.0458	0.90	0.6001	0.0775	0.80



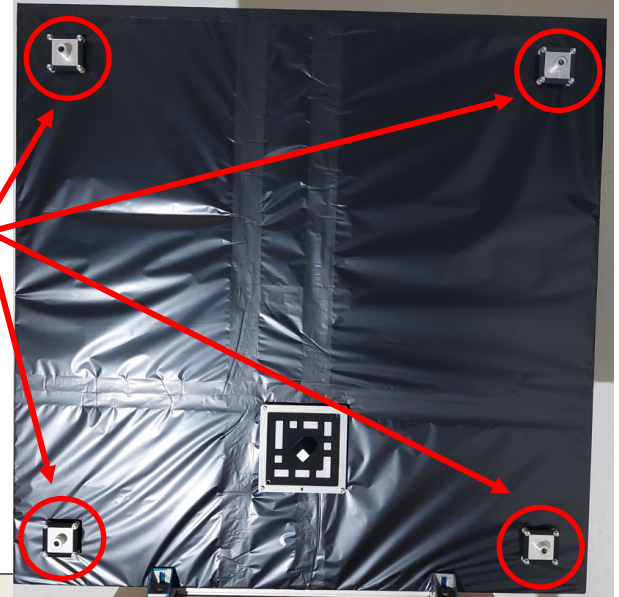
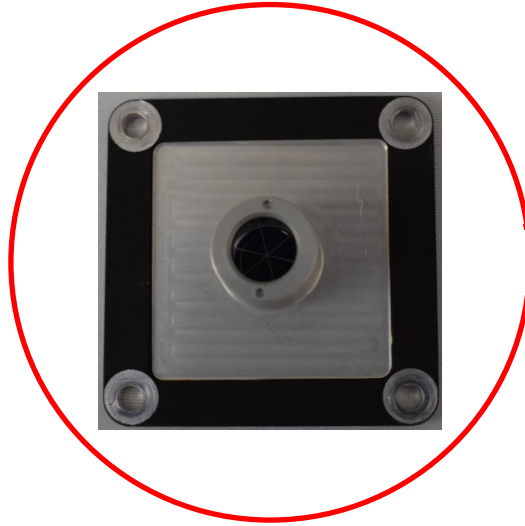
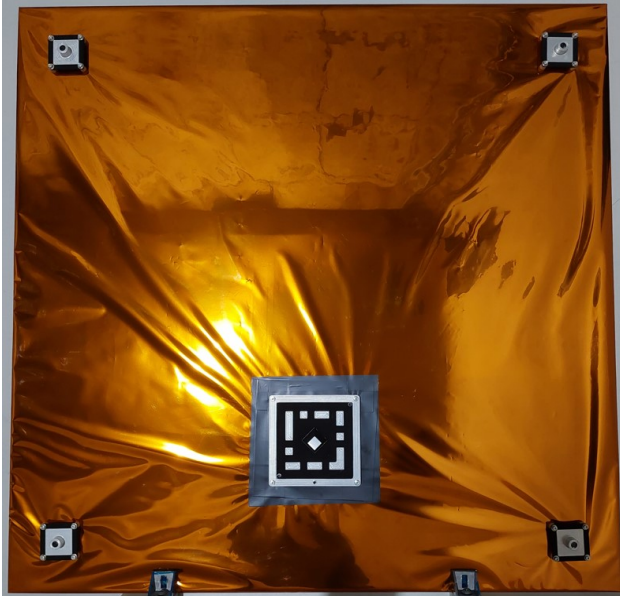
QUALIFICATION SUMMARY TABLE

No.	Description	P/N	S/N	Bakeout	Humidity	Vibration	TVAC	Shock
1.	3D Marker (Surtec 650+PNC)	MSN-223000	ADM-001 PT	PASS	N/A	N/A	PASS	N/A
2.	3D Marker (Surtec 650+PNC)	MSN-223000	ADM-002 PT	PASS	N/A	N/A	N/A	N/A
3.	3D Marker (Surtec 650+PNC)	MSN-223000	ADM-003 PT	PASS	N/A	N/A	PASS	N/A
4.	3D Marker (Surtec 650+PNC)	MSN-223000	ADM-001	PASS	PASS Visual failure*	PASS	PASS	PASS
5.	3D Marker (Surtec 650+PNC)	MSN-223000	ADM-002	PASS	PASS Visual failure*	PASS	PASS	PASS
6.	3D Marker (Surtec 650+PNC)	MSN-223000	ADM-003	PASS	PASS Visual failure*	PASS	N/A	N/A
7.	3D Marker (Surtec 650+AQ PUK)	MSN-223000	ADM-004	PASS	PASS	PASS	PASS	PASS
8.	3D Marker (Surtec 650+AQ PUK)	MSN-223000	ADM-005	PASS	PASS	PASS	PASS	N/A
9.	3D Marker (Surtec 650+AQ PUK)	MSN-223000	ADM-006	PASS	PASS	PASS (partially)	N/A	N/A
10.	2D Marker (Surtec 650+PNC)	MSN-213000	ADM-001	PASS	PASS	PASS	PASS	PASS
11.	2D Marker (Surtec 650+PNC)	MSN-213000	ADM-005	PASS	PASS	PASS	PASS	N/A
12.	2D Marker (Surtec 650+PNC)	MSN-213000	ADM-009	PASS	PASS	PASS	PASS	PASS
13.	2D Marker (Surtec 650+AQ PUK)	MSN-213000	ADM-010	PASS	PASS	PASS	PASS	N/A
14.	2D Marker (Surtec 650+AQ PUK)	MSN-213000	ADM-011	PASS	PASS	PASS	PASS	N/A
15.	2D Marker (Surtec 650+AQ PUK)	MSN-213000	ADM-012	PASS	PASS	PASS	PASS	PASS

3pcs of 2D and 3pcs of 3D Marker has been passed the whole qualification test sequence.



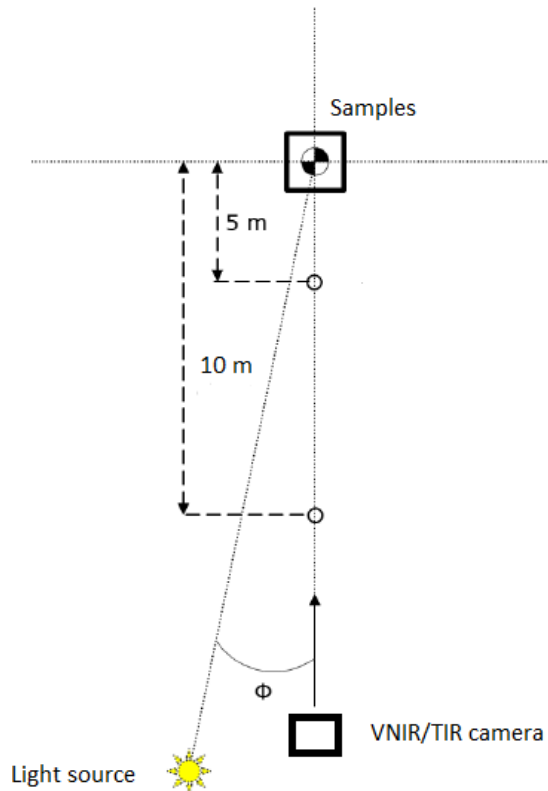
CONTRAST MEASUREMENT



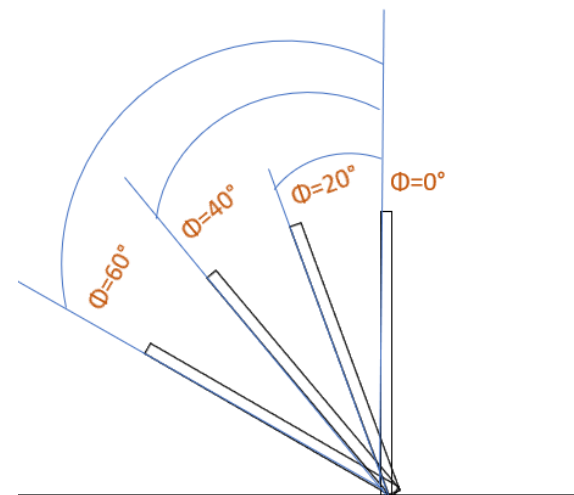
Description	P/N	S/N
2D Marker	MSN-213000	ADM-003
2D Marker	MSN-213000	ADM-007
2D Marker	MSN-213000	ADM-013
2D Marker	MSN-213000	ADM-014



CONTRAST MEASUREMENT



Pitch angles of test board





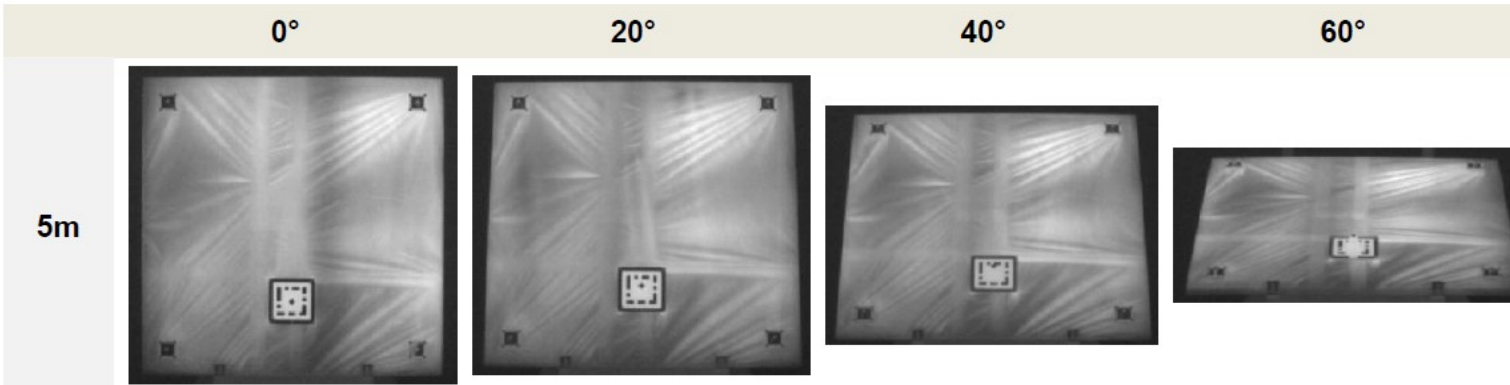
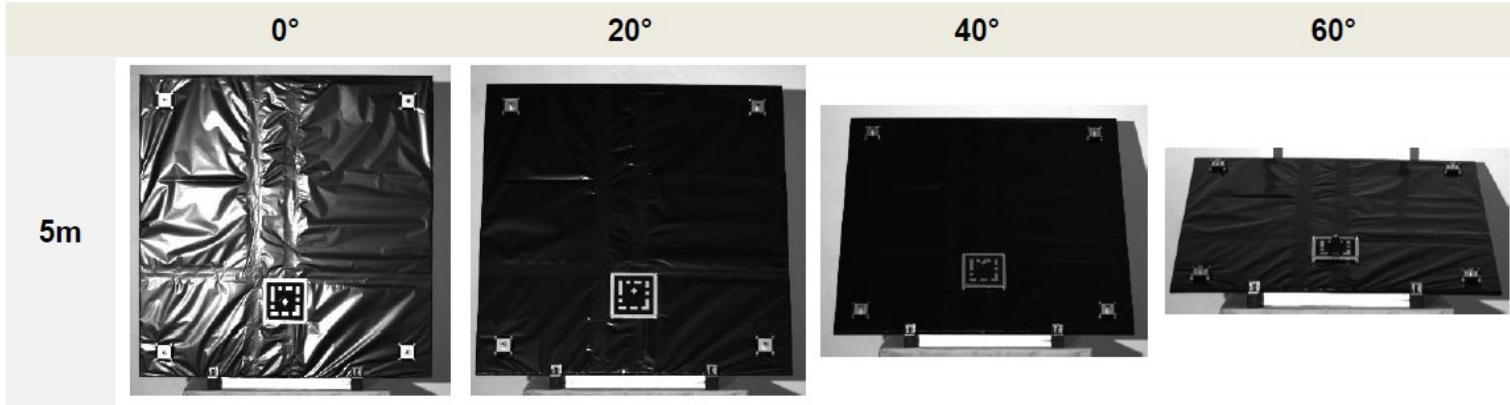
MSN

EQUIPMENT QUALIFICATION



Admatis

CONTRAST MEASUREMENT





CONTRAST MEASUREMENT

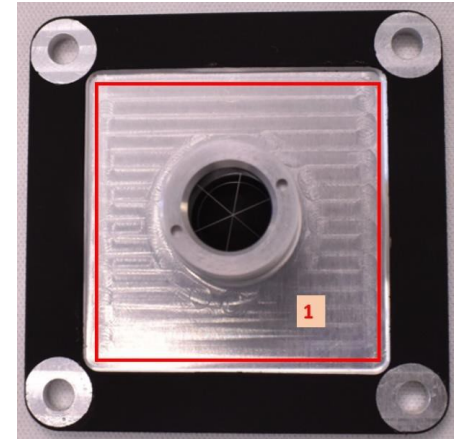
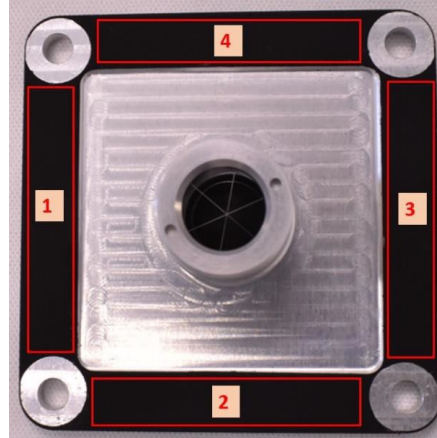
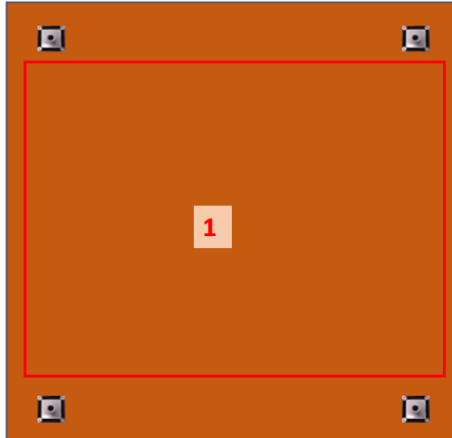
The evaluation is performed using the **Michelson Contrast** formula:
$$\frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

I: intensity (i.e. pixel gray value) [$0 < C < 1$]

I_{max} can be considered as average intensity value of the target, while I_{min} is the average intensity of the background.

Image processing software: **ImageJ**

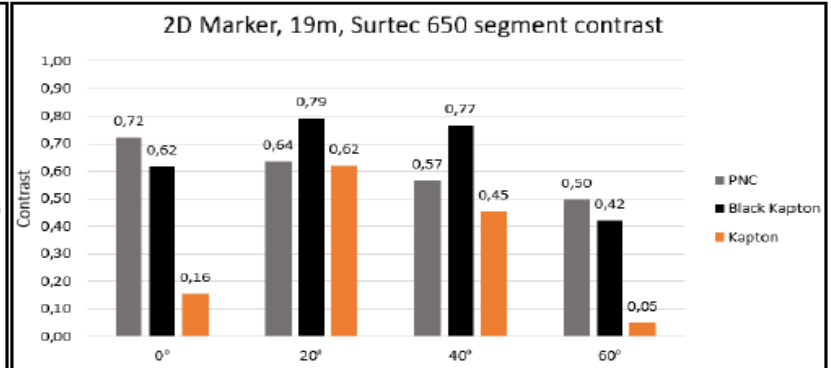
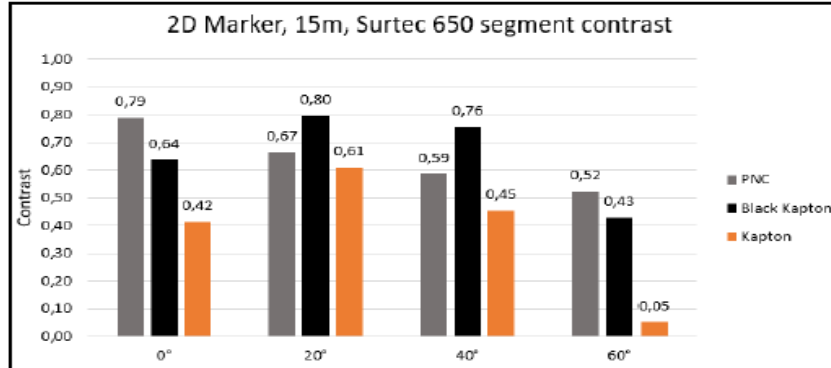
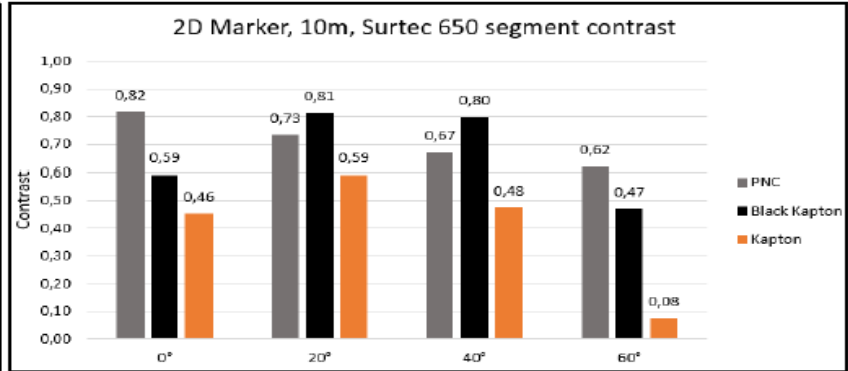
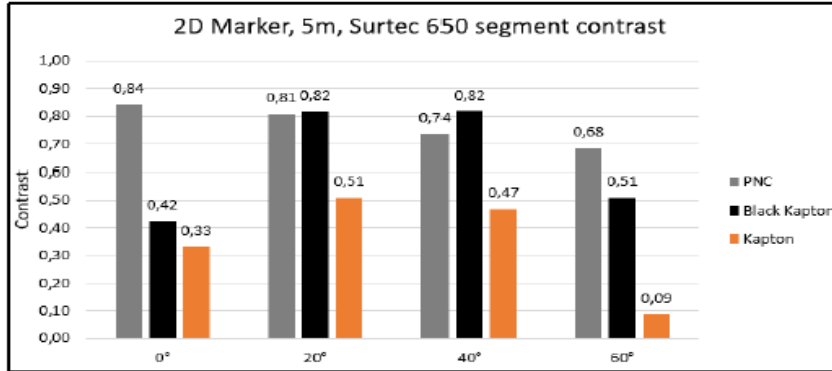
To calculate the average Intensities ROIs (Region of Interest) marked have been applied:





CONTRAST MEASUREMENT RESULT

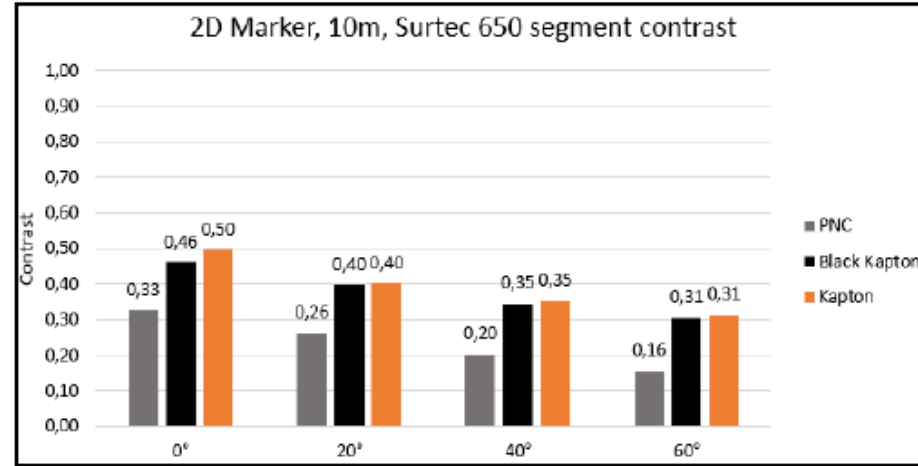
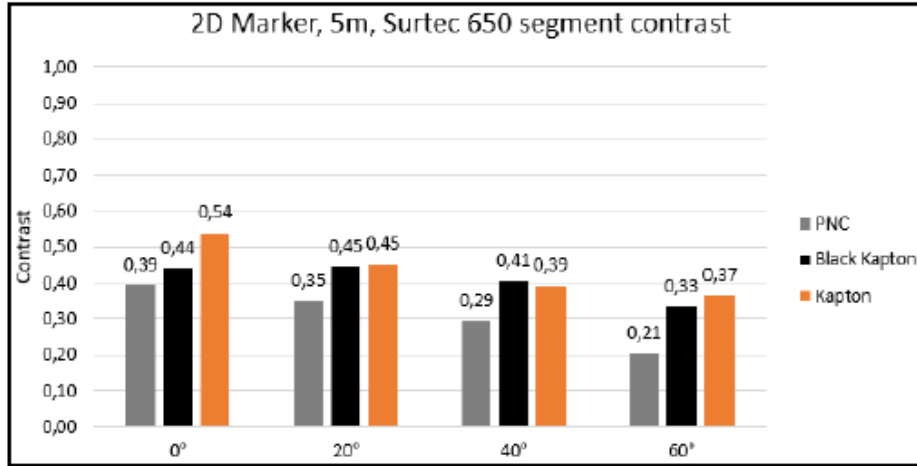
VNIR





CONTRAST MEASUREMENT RESULT

TIR





QUALIFICATION SUMMARY

- 3 pcs of 3D Markers and 3 pcs of 2D Markers went through the whole qualification test series. Remaining models have not been subjected of all tests.
- Bakeout of all models were successful.
- Visual failure has been identified after the humidity test on 3D Markers S/N ADM-001, ADM-002 and ADM-003. All remaining models subjected the humidity test passed the test successfully. As test chamber failure has been identified as the root cause of the NC and repeated humidity test was performed successfully, the humidity test of the subjected models have been declared successful.
- Vibration test has been performed in baseline (without thermal washers) configuration. All models subjected the vibration test passed the random qualification and sine test successfully.
- Thermal vacuum cycling and shock test has been performed successfully on the subjected models.
- Inspections and measurement between the tests showed no major deviations compared to the initial conditions.
- Based on the above the qualification of the 2D and 3D Markers against the HPCM requirements can be declared successful.



2nd GENERATION OF MARKERS

- Lowering of unwanted reflections of the Surtec coated parts of the markers with modification of surface roughness of the base material
- Application of inorganic black coating for the black parts of the markers
- CCR fixation in the LRR unit with glueing