Scan Mechanisms for the MetOP-SG instruments – Challenges and Qualification Status

Airbus Defence and Space – CoC Mechanisms Friedrichshafen
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DEFENCE AND SPACE

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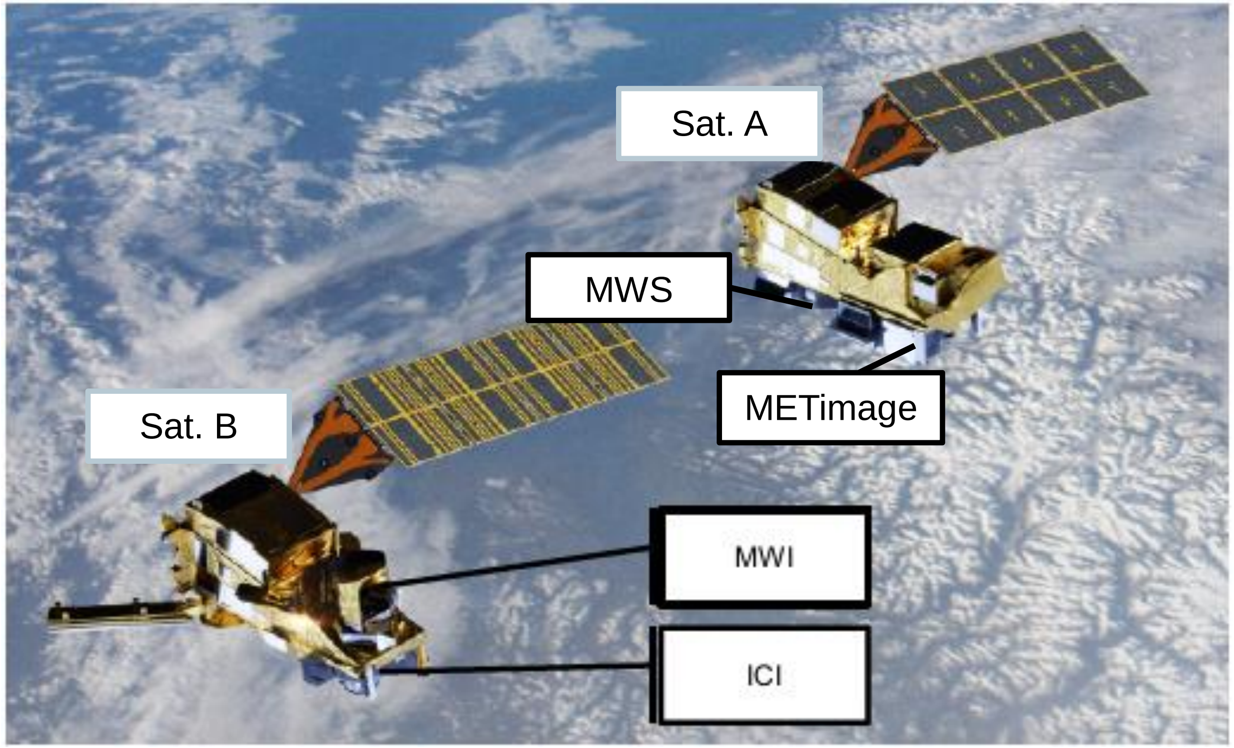
MetOP-SG instruments – CoC FDH overview

Scan Mechanisms for following four instruments to be flown on Metop SG – A and B Satellites have been developed:

- METimage (Visible Infrared Imager)
- MWS (Microwave Sounder)
- MWI (Microwave Imager)
- ICI (Ice Cloud Imager)

→ Focus on challenges and the qualification status of the various scan mechanism

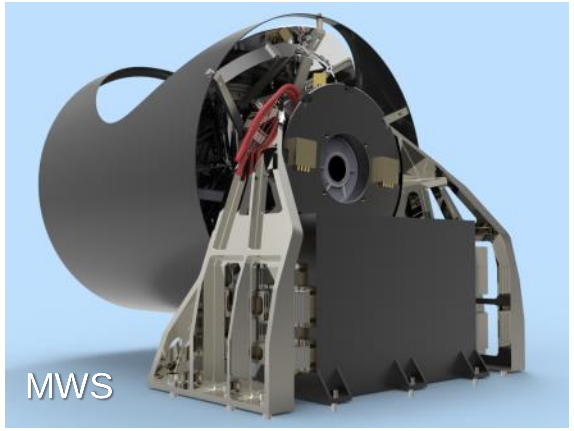


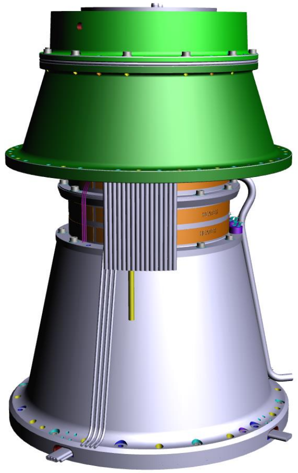
MetOP-SG Instruments – CoC FDH Design Approach

Wherever possible a commonality design approach has been sought for the different scan mechanisms of MetOP-SG developed and built at Airbus Defence and Space in Friedrichshafen in order to simplify engineering and management effort across the different projects

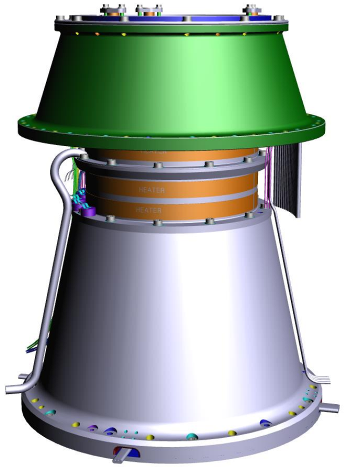
In particular following key components of the drive unit are either equal or very similar:

- Bearings – angular contact bearings
- Motors – brushless DC motor
- Encoders – high precision optical absolute encoder
- Electronics – Control Loop Design

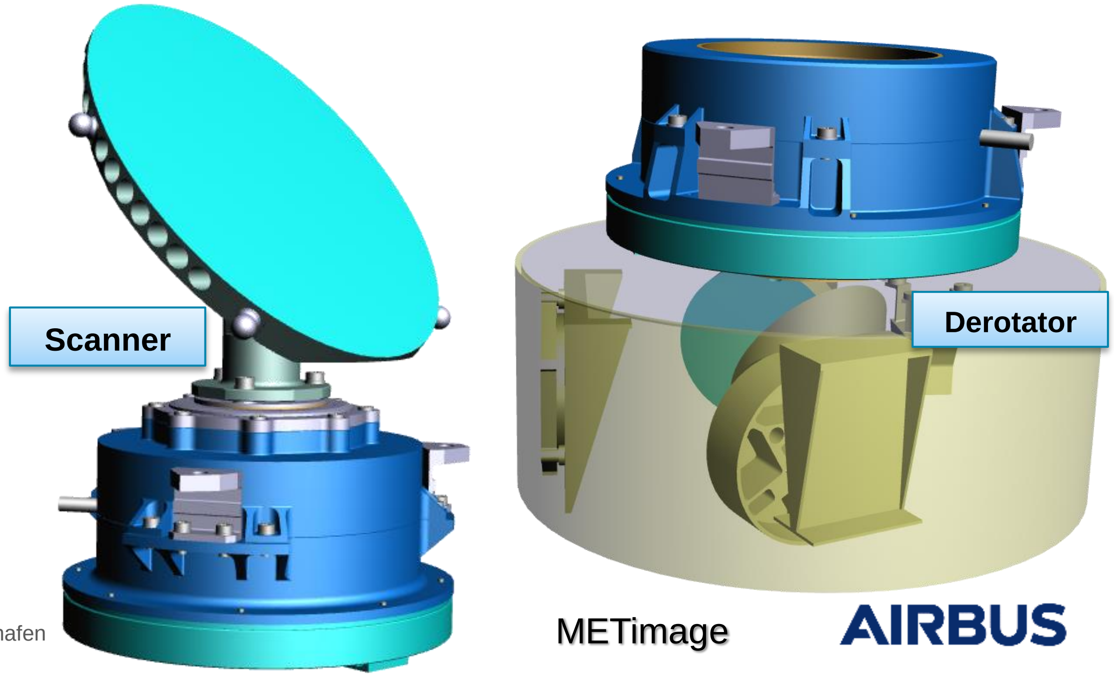




MWI



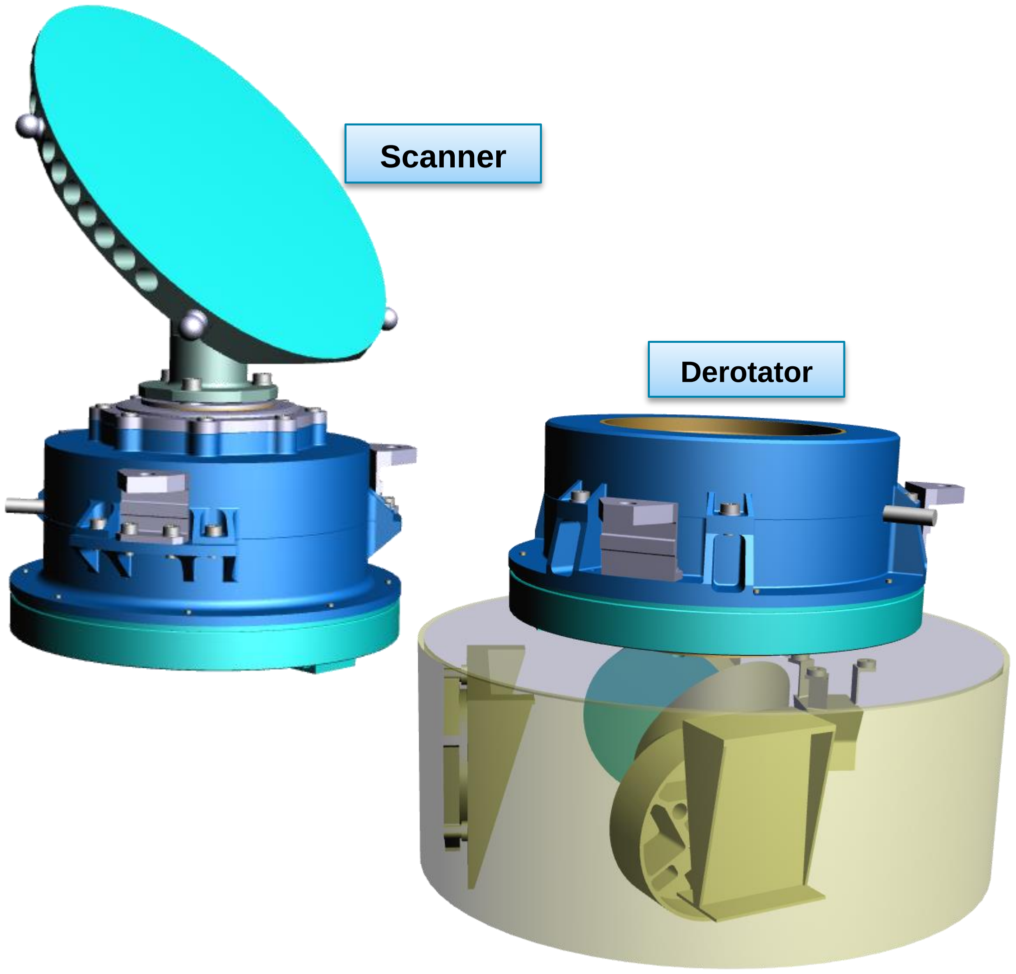
ICI



METimage

METimage Scanner and Derotator

METimage Scanners - Key Performances



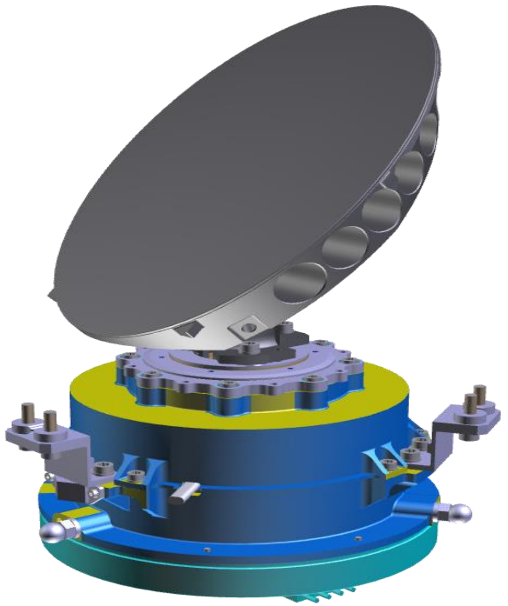
- High-accuracy across-track scanning and image de-rotation
- Highly dynamic operational profile (optimized for earth view scanning duration)
- 7.5 years life time
- Redundant motor coils and encoder
- High pointing accuracy
- Compact design with minimized mass
- Electronically synchronized mechanisms (2:1)

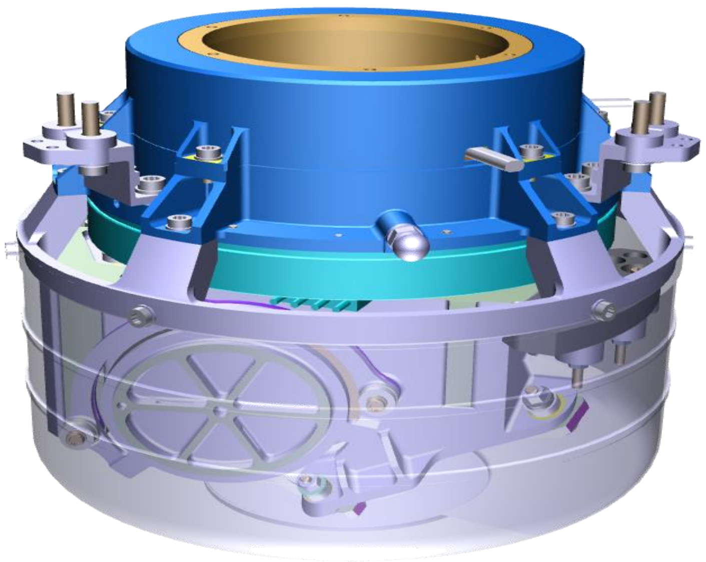
Mechanical Dimensions Scanner / Derotator		
Rotation Envelope	⌀ 210 / ⌀ 300	mm
Mechanism Height	340 / 200	mm
Mechanism Mass	9 / 10.5	kg
Scanning Characteristics		
Earth View Angle	108	deg
Absolute performance error	< 80	µrad
Earth View Scanning Velocity	~ 158	deg/s
Wave Length	443 – 13,345	nm

METimage Scanners - Design

Each rotating mechanism consists of

- Drive Unit
  - Structure
  - Brushless DC motor
  - Ball bearings
  - Absolute optical encoder
- Optics
  - Scanner Mirror for Scanner Mechanism
  - Derotator Mirror Assembly for Derotator Mechanism





Modular approach

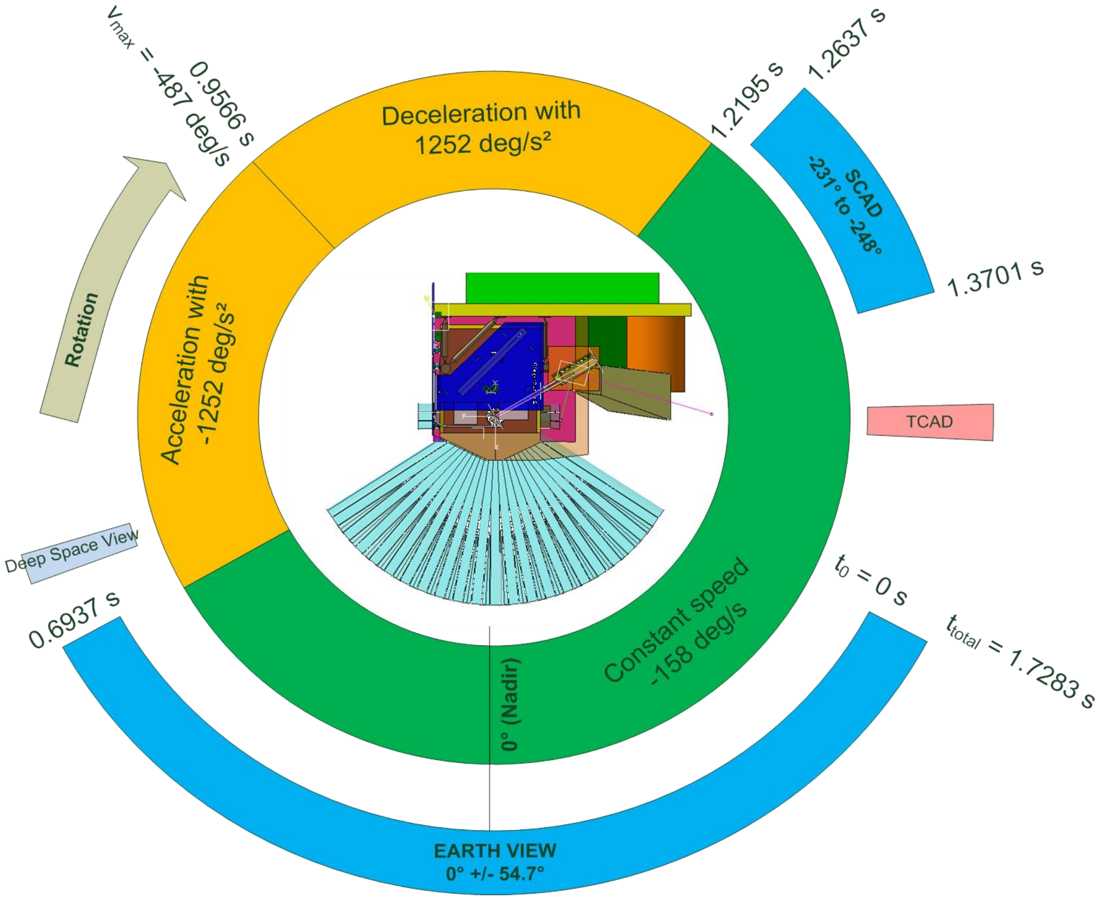
- Drive Unit concept identical to other Airbus Friedrichshafen scanners
- Derotator design adapted to accommodate optical path, increase lifetime and decrease power consumption (bearing pair in back-to-back layout)

METimage Scanners - Challenges

- Discontinuous scanner with dynamic scan profile
- Scanner and Derotator rotation synchronized
  ➔ Scanner rotates at two times the speed of the Derotator (1.73 seconds per revolution)

- Scanner and Derotator operate independently of each other
  ➔ synchronized by common RSYNC (clock) once per revolution of Scanner
  ➔ no mechanical connection between mechanisms

- Key challenges for mechanisms:
  - Random (non-periodic) wobble: ☺
    - <10 µrad peak-peak for Scanner (tested: <7 µrad) ☺
    - <25 µrad peak-peak for Derotator (tested: <10 µrad)
  - Performance Drift Error – to be verified by test
    - <25 µrad for Scanner
  - Scanner mirror surface error: 0.4 nm RMS – to be verified by test
  - Derotator mirror assembly alignment – to be verified by test



Scanner profile

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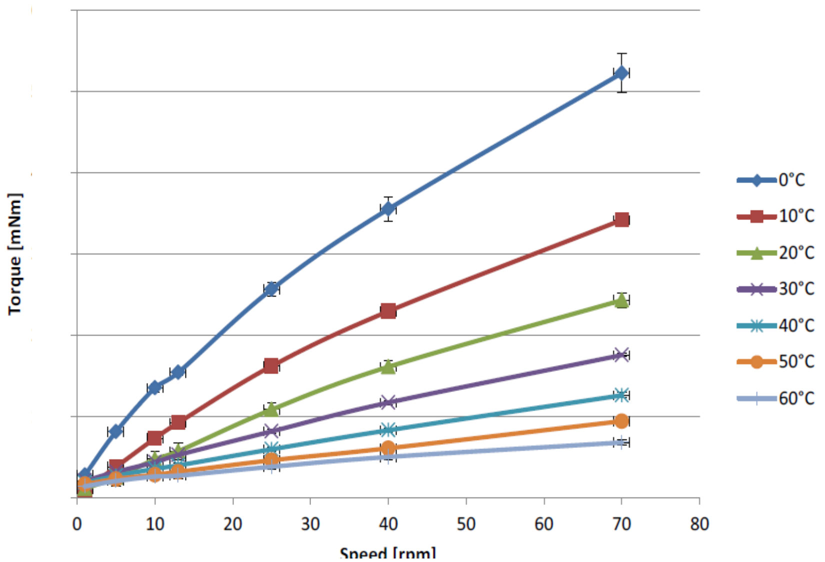
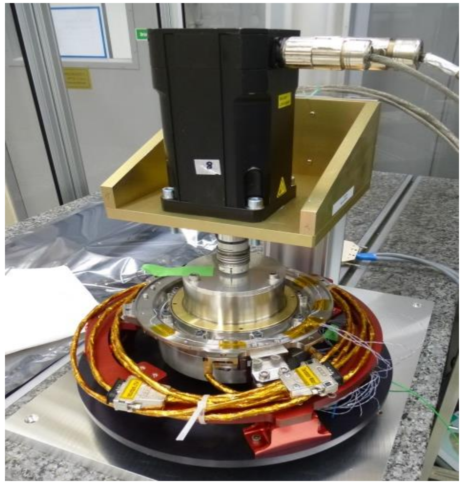
METimage - Qualification Status

- Bearing friction measurements performed for both mechanisms (dry nitrogen atmosphere)
- Environmental test campaign of Scanner and Derotator Life Test Models completed successfully
  - Sine vibration
  - Random vibration
  - TV cycling
  - Resistive torque and wobble prior and subsequent to all tests consistent
- Life Test of Scanner mechanism: ~15 Mio. revs performed (target: 200 Mio.)
- CDR held in February 2019
- Manufacturing of flight models started



Derotator LTM Bearing Friction Data



Bearing Friction Test Setup

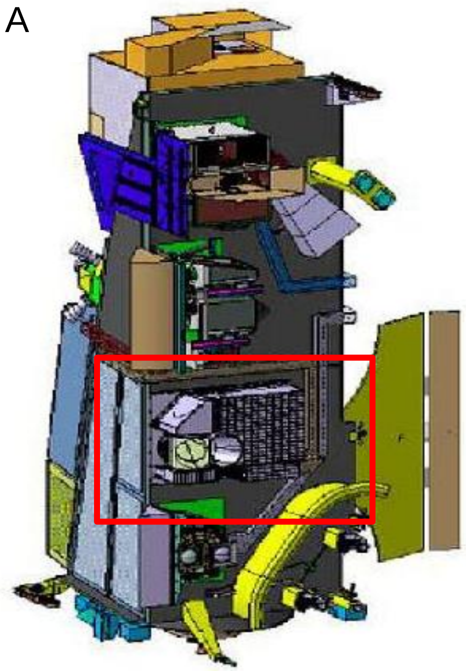
MWS Scanner

Microwave Sounder Mechanism – Design

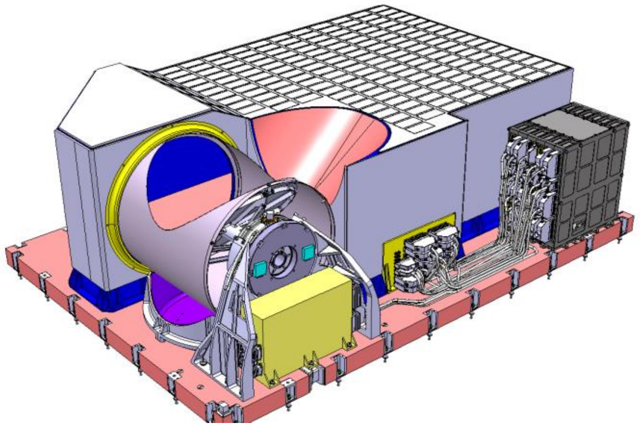
Mechanism Components
- Drive Unit
  - Structure
  - Brushless DC motor
  - Ball bearings
  - Absolute optical encoder
- Scan Control Electonics
  - Cascaded closed loop controller design
- Reflector Unit
  - Plane RF Reflector: Aluminum coated CFRP Sandwich providing reflectivity for 24 channels from 23 GHz up to 230 GHz.
  - Lightweight CFRP Stray-Light Shroud

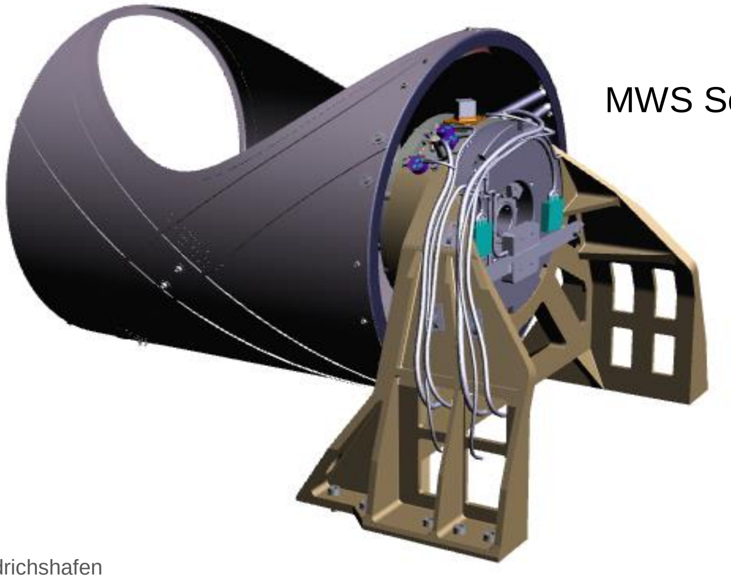
Modular approach
- Drive Unit concept identical to other Airbus Friedrichshafen scanners

Sat. A



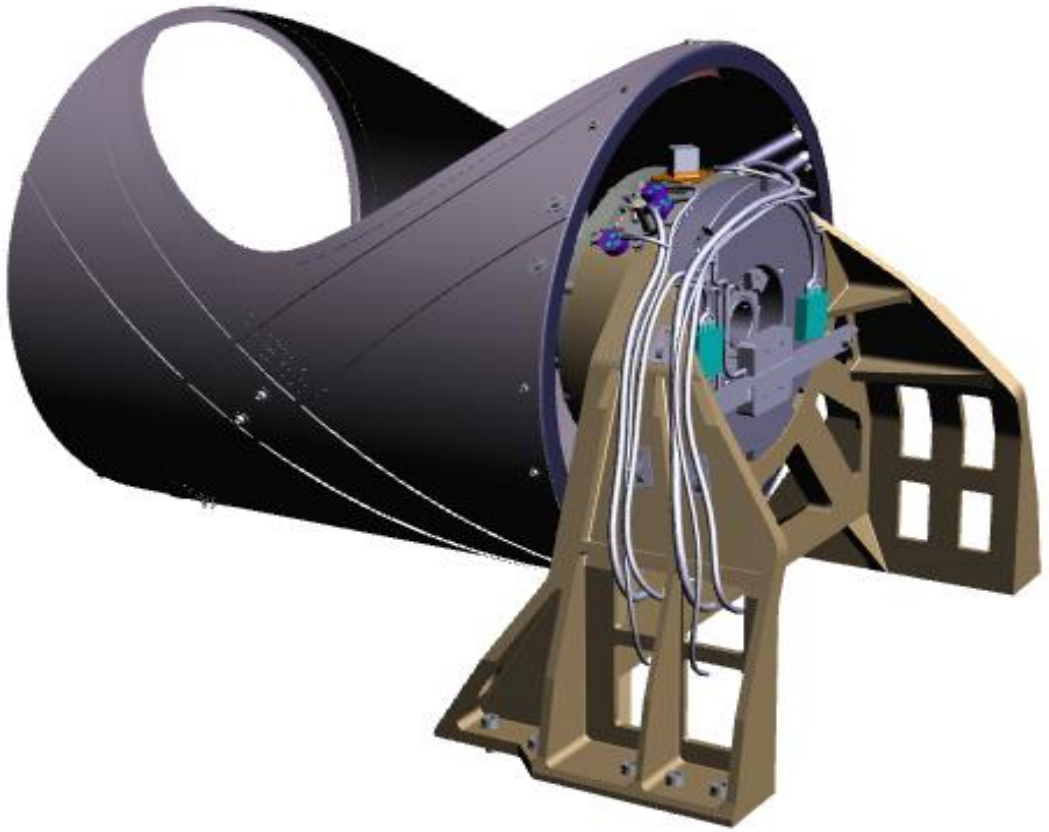
MWS





MWS Scan Mechanism

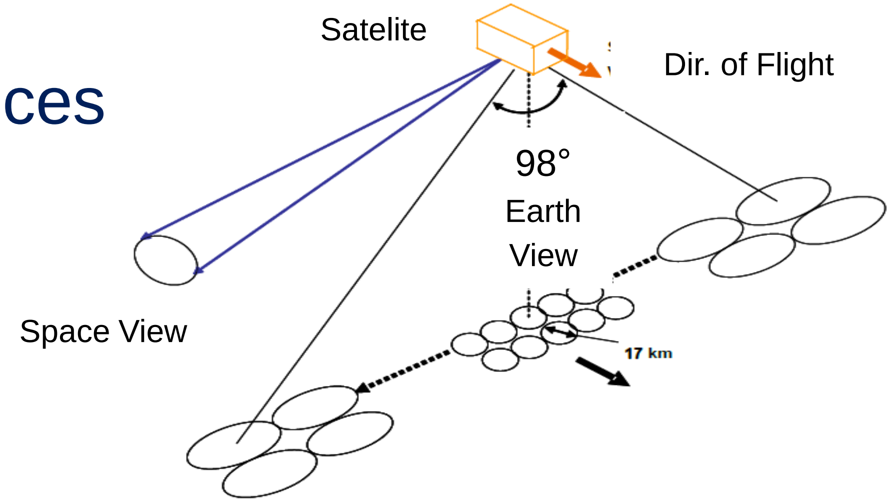
Microwave Sounder Mechanism - Key Performances



- High accuracy across-track scanning
- Highly dynamic, non-uniform scan velocity profile (maximize earth view)
- 19 years Long Term Storage capability
- 7.5 years in orbit operation with

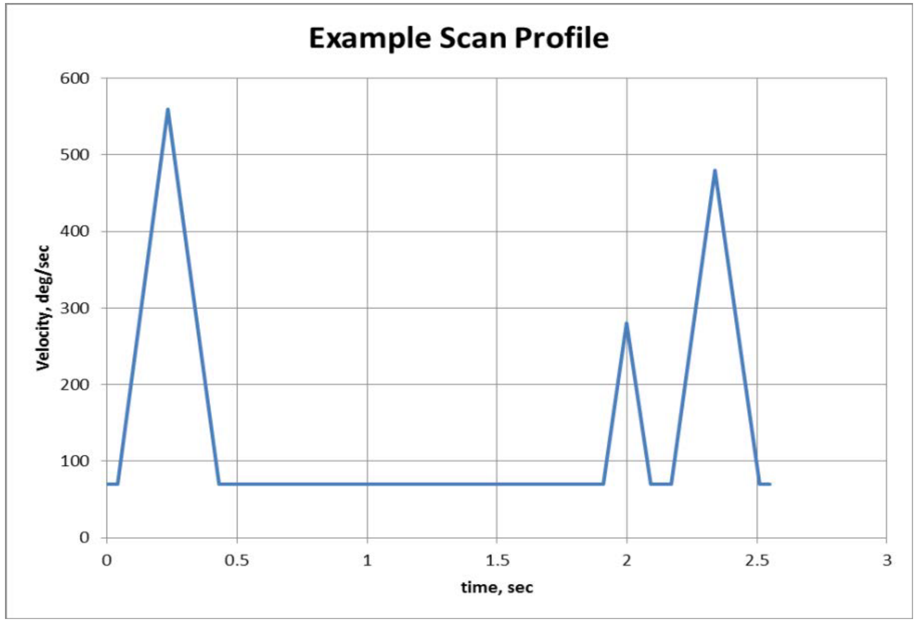
Mechanical Dimensions		
Rotation Envelope	⌀ 371	mm
Mechanism Height	531	mm
Mechanism Mass	16	kg
Scanning Characteristics		
Earth View Angle	98	deg
Pointing Accuracy	< ±0.01	deg
Maximum Earth View Scanning Velocity	~ 73	deg/s
Velocity Consistency	~ 0.75 (1.75% required on Metop-SG)	%
RF Characteristics		
Frequency Range	23 - 230	GHz
Insertion Loss	<0.5	dB
Power Consumption	< 95 (peak) < 35 (average)	W

Microwave Sounder Mechanism - Key Performances



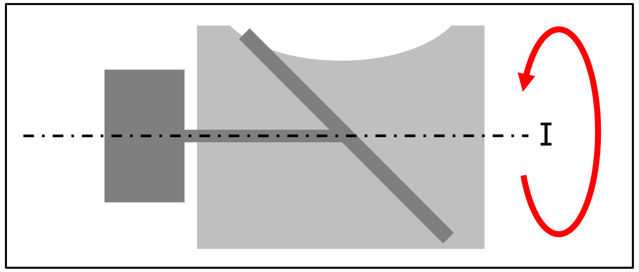
Operational Mode: Across Track Scanning

- Constant velocity in Earth View (98°)
- Constant velocity in 2 Calibration Views, OBCT (hot cal.) and Deep Space (cold cal.)
- Acceleration and decceleration phases between views to maximize observation time

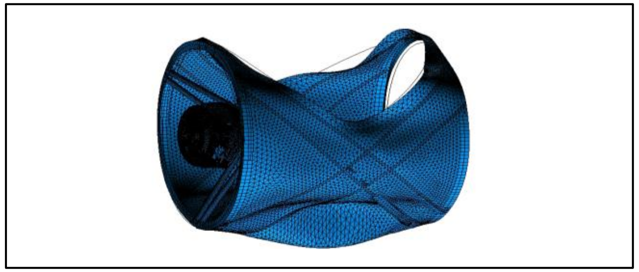


Microwave Sounder Mechanism - Challenges

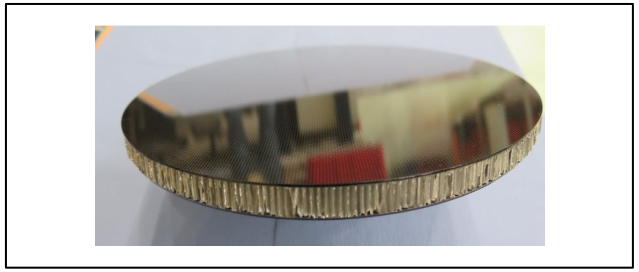
1. Minimization of rotating Inertia to minimize
   - Peak Power Consumption
   - Exported Loads



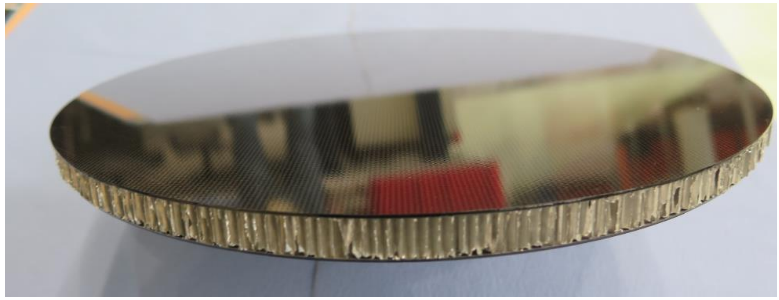
2. Stiffness Requirement:
   - first mode > 100Hz
   - 100Hz < modes < 140 Hz: max. 10% eff. Mass.



3. Coated lightweight reflector required
   - Roughness: <1µm
   - Flatness: <8µm (rms)

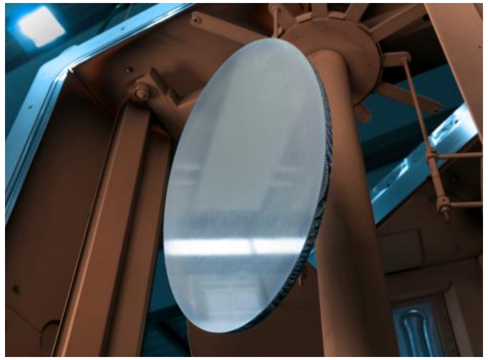


Microwave Sounder Mechanism - Challenges



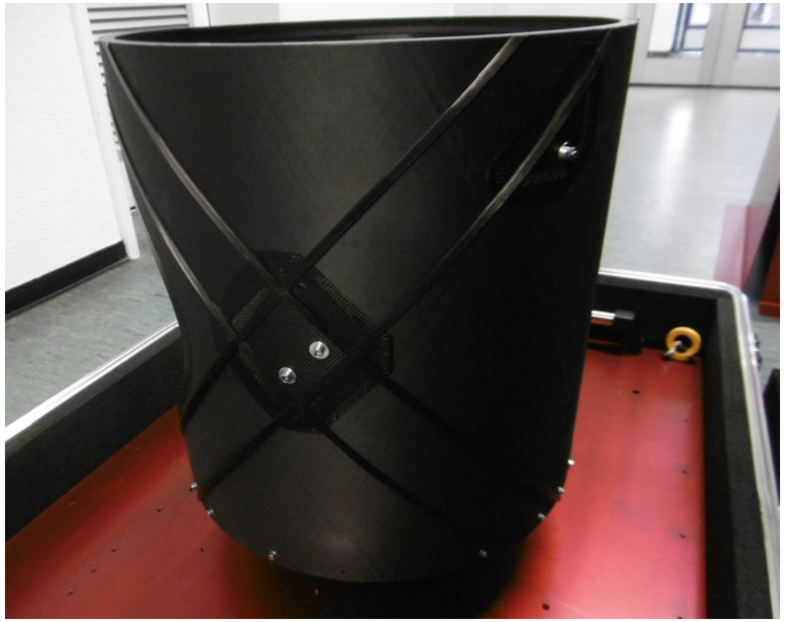
Light-Weight Reflector and Shroud Design

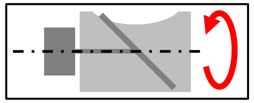
- Flat reflector: CFRP-Sandwich



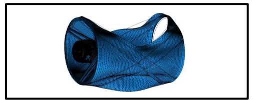
- Reflector Coating: Vapor Deposited Aluminum method

- Stray-Light Shroud: wall thickness: 0.3mm
  high modulus Fiber
  load optimized fiber layup
  fiber placement manuf. method
  unidirectional reinforcements

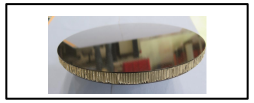




Low Mass



High stiffness
→ Low Inertia



Planarity

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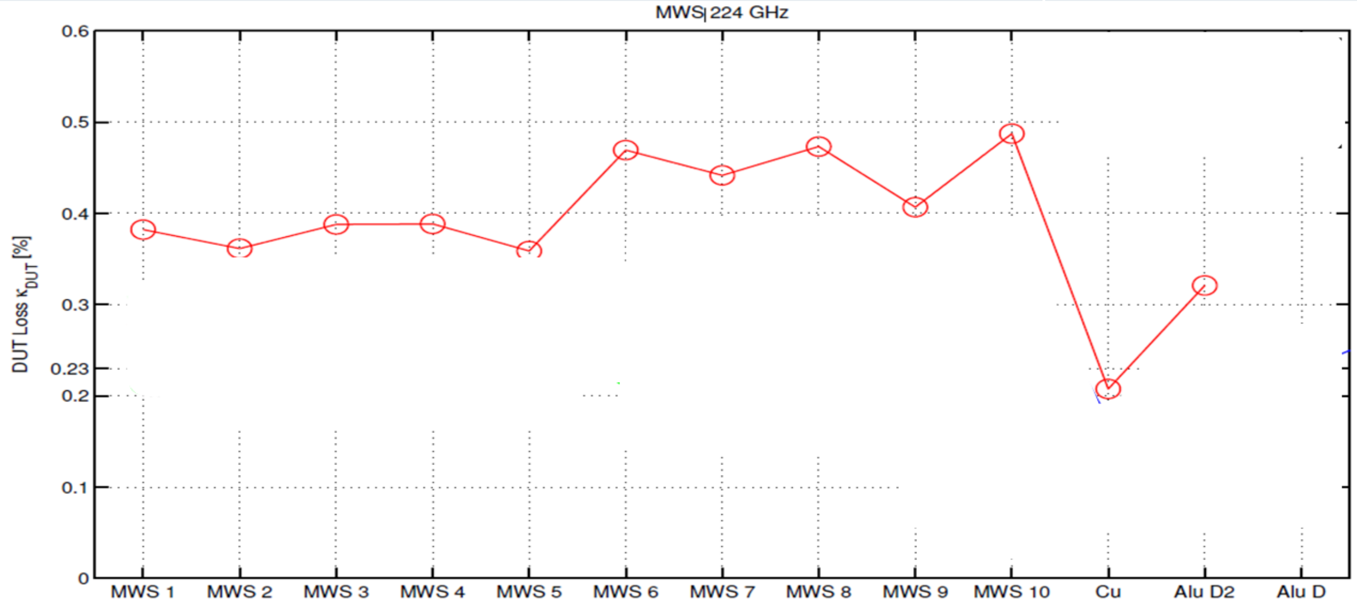
Microwave Sounder Mechanism - Qualification Status

Reflector Coating Qual.: Complete, Successful

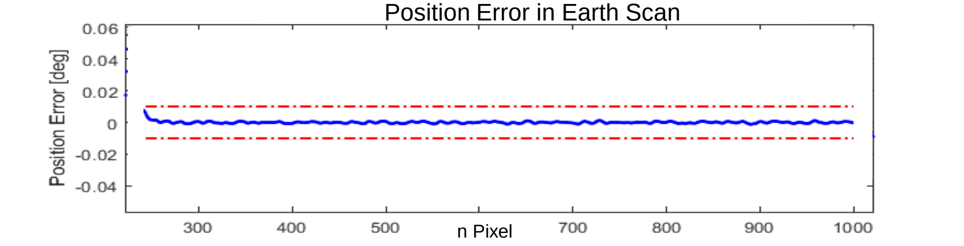
Test	Objective	Status
Damp Heat Test	Corrosion Resistance	**Passed**
Thermal Cycling	Thermal Stability	**Passed**
Micro Sectioning and Visual Inspection	Check for damages and delamination	**Passed**
Reflectivity Measurements	RF Performance	**Passed for low frequencies** **Refl. Requirement not fully met high frequencies**



RF performance for 10 coated samples, 1 Cu reference sample, 2 Al reference sample @ 224 Ghz

Microwave Sounder Mechanism - Qualification Status

Mechanism Qualification: Ongoing

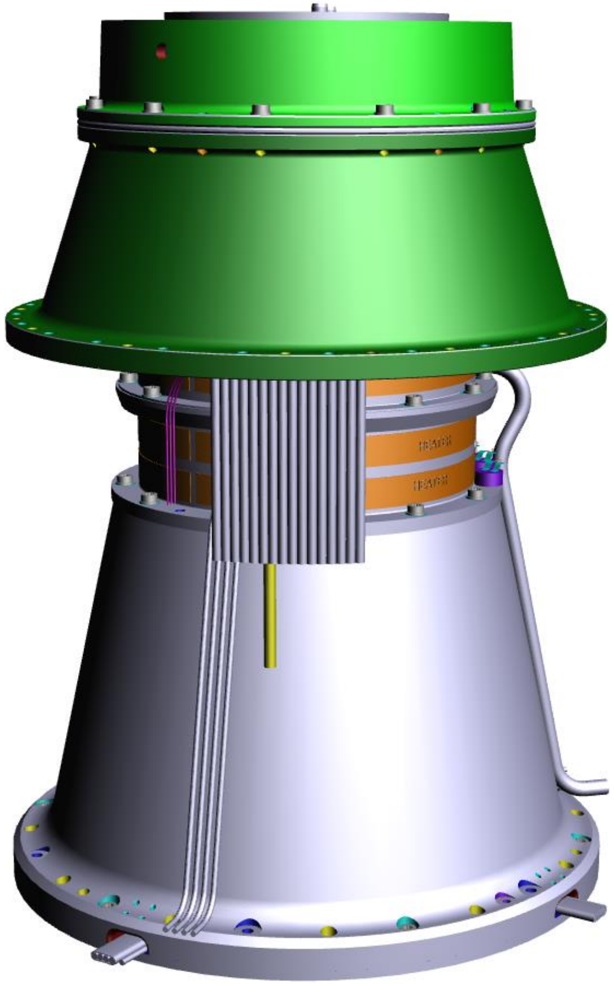
Test	Test Result Detail	Status
Function and Performance		Passed
TV	-	Passed
EMC	-	Passed
Shock	-	Passed
Vibration	• Modal behavior already proven in vibration Pre-Tests (sin-sweeps and low level runs) • Model and Hardware show good correlation • Final Qual. Testing: open	Open
Micro-Vibration	-	Open
Life Test	-	Open

Lesson Learned:

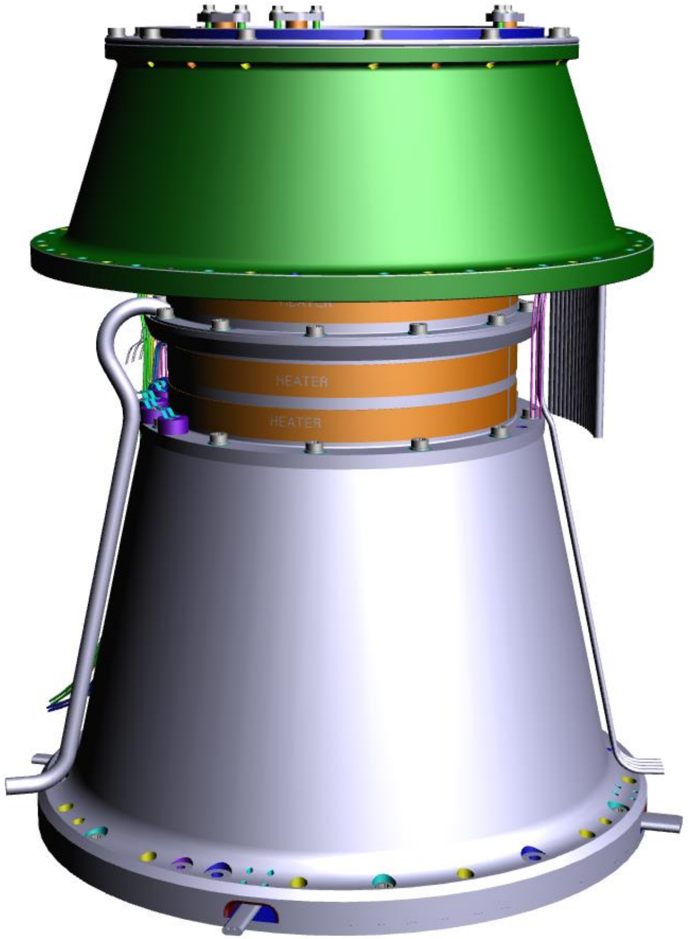
- Heritage design had a full aluminum shroud and reflector, significantly smaller in size
- Structural effects of upscaling the design were underestimated → change to CFRP required

MWI and ICI Scanner

MWI/ICI Scanners - Key Performances



MWI



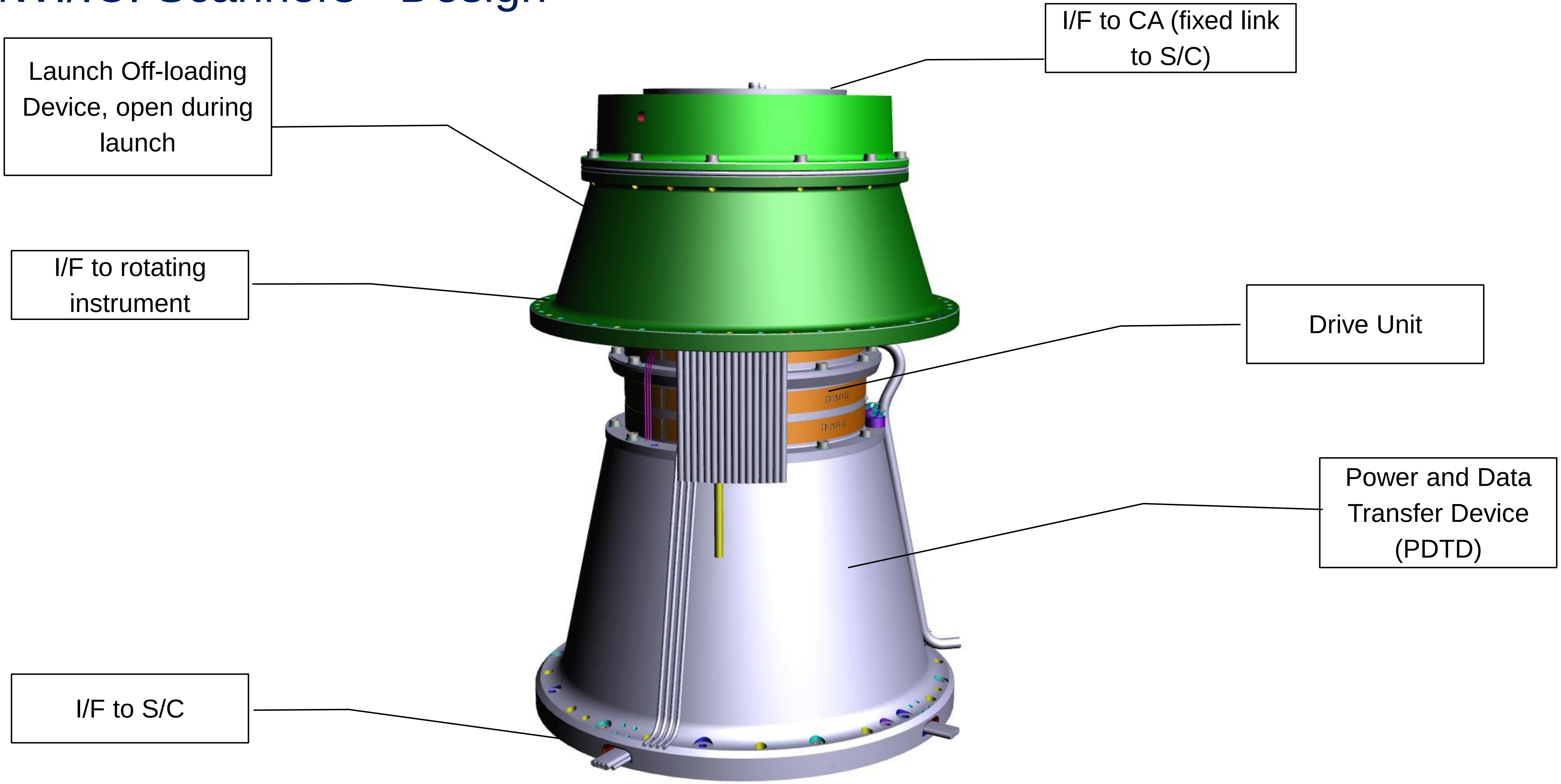
ICI

Mechanism

- Bearing Offload Device (low preload – long lifetime)
- Special Feature for supporting “Calibration Unit” during launch
- Power & Data Transfer via Rollring (for long lifetime)
- Redundant motor coils and encoder
- High velocity constancy
- Very high accuracy reference positioning
- Compact design with minimized mass

Mechanical Dimensions		
Diameter	320	mm
Mechanism Height	500	mm
Mechanism Mass	30	kg
Scanning Characteristics		
Scan Accuracy	< 0.001	deg
Maximum Pointing Velocity	47.3	rpm
Speed Stability	25	ppm
Life Characteristics		
Lifetime	7.5	Years
Long Term Storage	19	Years

MWI/ICI Scanners - Design



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MWI/ICI Scanners - Challenges

- High rotational constant speed stability for long life of 7.5 years in orbit (~180.000.000 rev)
- Different rotational mass (60 – 160 kg) and inertia (3 – 25 kg m2)
- Supporting a heavy On-Board Calibration Unit located eccentrically on top of the stator part
- Transfer of power and LVDS signals to the rotating parts of the instrument via PDTD
- Motor magnet corrosion – solved by changing the motor magnet material to CoSm
- Motor stator corrosion – solved by applying Parylene coating additionally to Nickel layer

- Challenging harness routing due to amount of cable to be routed through the mechanism + moving harness (LOD) – good skills and much experience of harness staff needed to route the harness in a proper way

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MWI/ICI Scanners – Qualification Status

- Current Model Status:

Scan Mechanism Model	Status	Remark
Structure &Thermal Model	Successfully tested and delivered to customer	Already delivered to Customer
Life Test Model/Pre-Dev Model	Test campaign successful; life-test ongoing	Already 140 mio. revolutions performed (80% of nominal in-orbit time)
EM MWI	Nearly fully tested	Outstanding is the last functional and performance check with SCE EM
EM ICI	Nearly fully tested	Outstanding is the last functional and performance check with SCE EM
EQM	Currently in qualification campaign	Alignment Check, Electrical IF Test, Vibration Test, Shock Test, Functional and Performance Test have been successfully performed
PFM MWI	Integration is ongoing	
PFM ICI	Integration is ongoing	

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MWI/ICI Scanners – Qualification Status

Life Test since Nov. 2017

- Achieved revs: 140 Mio. → 96 Mio. to go
- Last functional tests performed October 2018
- Motor current ☺
- BERT ☺
- Electrical Test ☺
- LVDS ☺

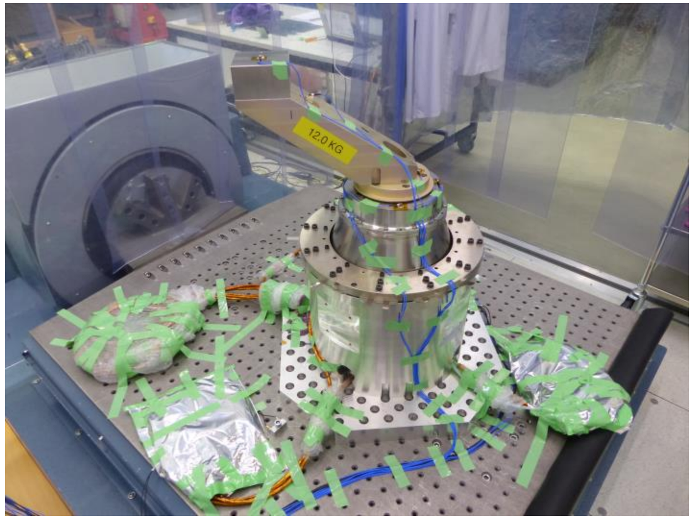
→ The mechanism health status is still in very good condition

MWI/ICI Scanners – Qualification Status

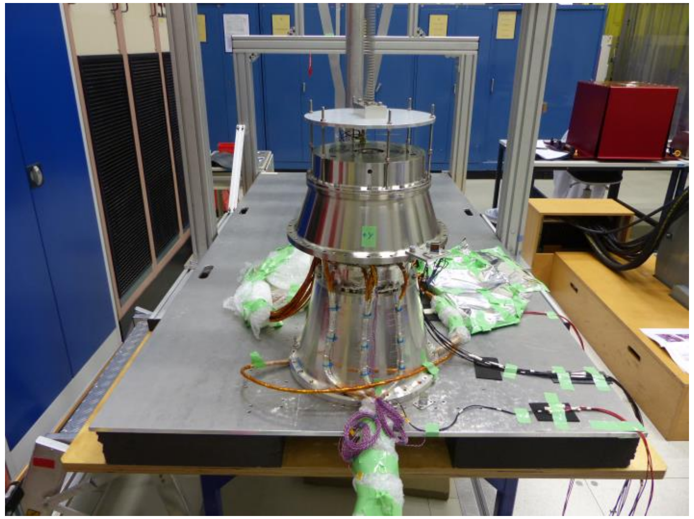
Vibration and Shock Test

- Challenge: 12kg mass off centered + non linear behaviour
- Preload: 7kN ± 0.3 kN
- Sine vibration: max. 12 g, 2 oct/min., 5-100 Hz
- Random vibration loads:
  - 4.34 grms in plane X, 120 seconds
  - 4.32 grms in plane Y, 120 seconds
  - 6.28 out of plane, 120 seconds
- Accumulated life test:
  - 2x Sine PFM
  - Sine Acceptance
  - 2x Random PFM
  - Random Acceptance

- Shock test:
  - SRS, max. 1000 g, 3 shocks per axis
  - Max misalignment after shock 0.0029°



MWI SCM EQM Vibration Test

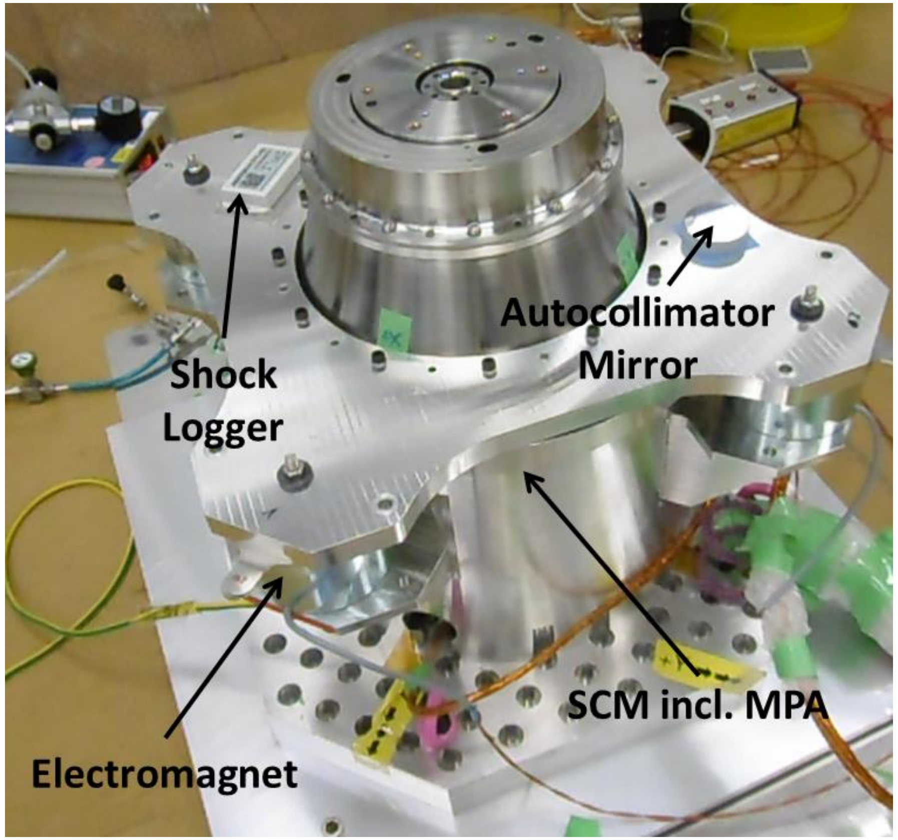


MWI SCM EQM Shock Test

MWI/ICI Scanners – Qualification Status

Release Test

- Challenge: angular release repeatability of less than 0.005 deg
- Preload: 7kN ± 0.3 kN
- Pointing repeatability of 26 releases:
  - Mean: 63.2 µrad (0.0036 deg)
  - 1σ: 16.4 µrad (0.0009 deg)
- Shock Measurement:
  - Treshold value: 2g (t ≥ 10ms)
  - The evaluation showed <u>no</u> shock as a result of release

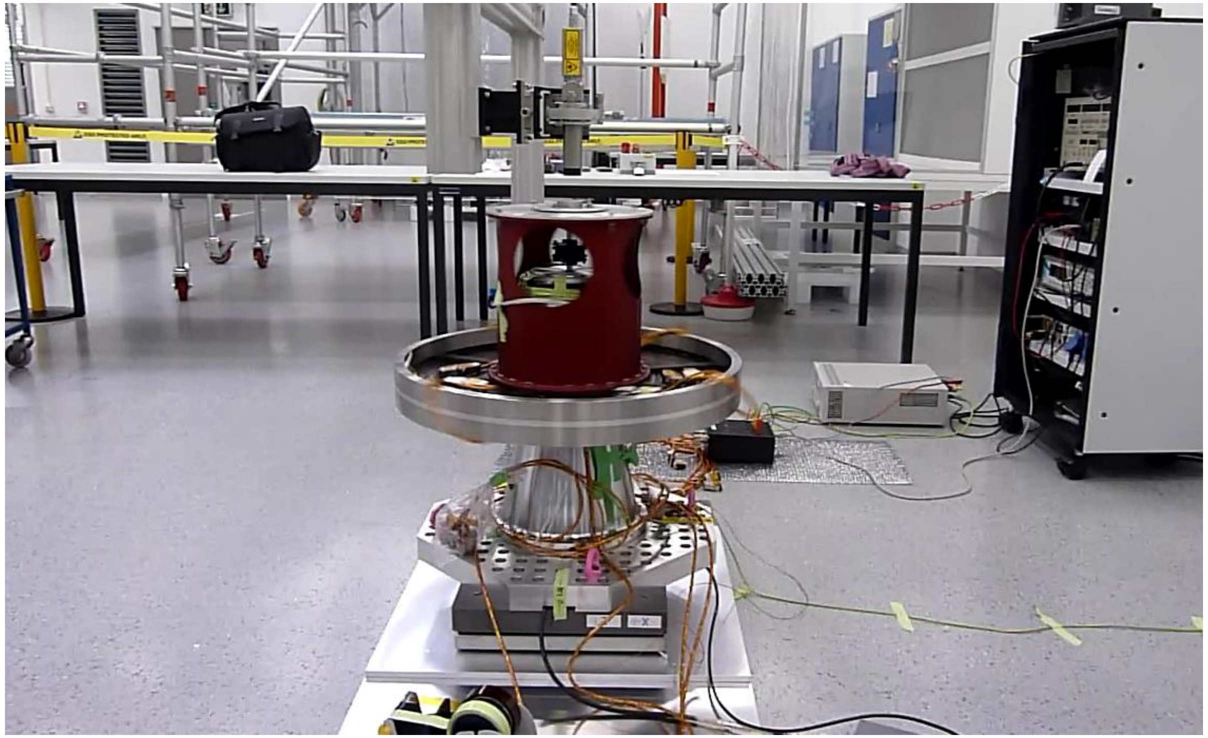


→ Pointing repeatability (standard deviation value) is clearly within the specified range and also below the mentioned APE value of the pointing budget.

MWI/ICI Scanners – Qualification Status

Full Function and Performance Test with MWI max. (25kgm ²) & ICI min. Inertia (3kgm²):

- ✓ Scan Pointing Performance
- ✓ Instantaneous/Average Scan Speed Stability
- ✓ Scan-Axis Steady Pointing
- ✓ MWI Inertia Specific configuration 1deg tilt
- ✓ Maximum Exported Forces/Torques
- ✓ SCE power Failure Torque < 0.6 Nm
- ✓ RAT Signal Position and Repeatability
- ✓ Mode Transitions
- ✓ PDTD Test (LVDS Bit-Error-Rate, Signal Quality, Voltage Drop)



Scan Mechanisms for the MetOP-SG instruments - Conclusion

- Commonality approach is challenging as different instruments come along with different requirements
- Still it was possible to gain maximum benefit using same mechanisms drive design concept with common key components as bearings, motor, encoder and electronics
- Concurrent communication and lesson‘s learnt **improved quality** and **reduced engineering** effort
- Common MAIT approach helped to create a **standardized processes** for scanner mechanisms at ADSF

Thank you

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