



11th ESA Workshop on ADCSS TERMA NEXT GENERATION STAR TRACKER USING APS

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TERMA[®]
ALLIES IN INNOVATION

ESA APS Star Tracker Studies



2nd Generation APS STR - Optical Head

The objectives of the work in this project were:

- To design and demonstrate via the manufacture and test of an engineering model, a second generation advanced, low cost and easily accommodated APS based optical head and baffle incorporating the technological advances identified in the pre-cursor activities.
- To produce an early BB based on the existing LCMS detector to provide early design de-risking in time for the CDR

Miniature Active Pixel Sensor based Star Tracker Engineering Qualification Model Development

This Activity has the following objectives for Phase 1 and Phase 2.

Phase 1:

- The development and demonstration of robust, high performance star tracker algorithms optimised for use with the Faint Star APS detector (but also compatible with the LCMS detector) and taking into full account all the in-flight lessons learnt from the CryoSat-2 experiences.
- The design of a miniature, yet low recurring cost, Electronics Unit (EU) capable of operating at least one star tracker optical head and running all of the required software functions and algorithms in a timely manner.
- The de-risking of the EU design via detailed analyses together with the manufacture and test of an Electrical Model.

Phase 2:

- To have a full STR equipment (OH + EU + S/W), fully tested and demonstrated to TRL6 (including environmental, performance and night sky testing).

OH Overview



Design drivers/goals:

- Highly miniaturized using single-chip radhard APS detector (LCMS or Faint Star)
- Maintain competitive accuracy, < 2 arcsec EOL
- Provide very high thermal stability
- Low parts count for high reliability
- No active cooling → much simpler design
- Low power
- Easy accommodation next to payload
- Optimize for large volume production



Dimensions:

- Body: Ø60 mm
- Footprint: Ø92 mm
- Height: 69 mm
- Mass: 310 g

OH Design – Structural Design



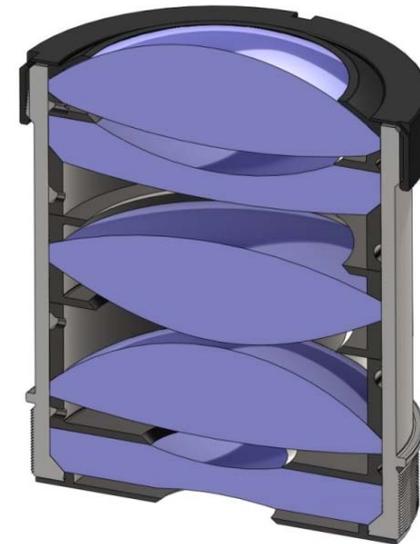
- The camera head design is boresight rotation symmetric
- Use of titanium for all structural and opto-mechanical parts
- Kinematic mounting feet
- Total mechanical isolation of the stray light baffle from the camera head
- Low mass and low power consumption
- Few structural parts, all designed for easy manufacturing in a standard universal CNC. The design is free from rectangular boxes requiring inefficient handling in a standard CNC milling center, or requiring very specialized machines for cost efficient production.



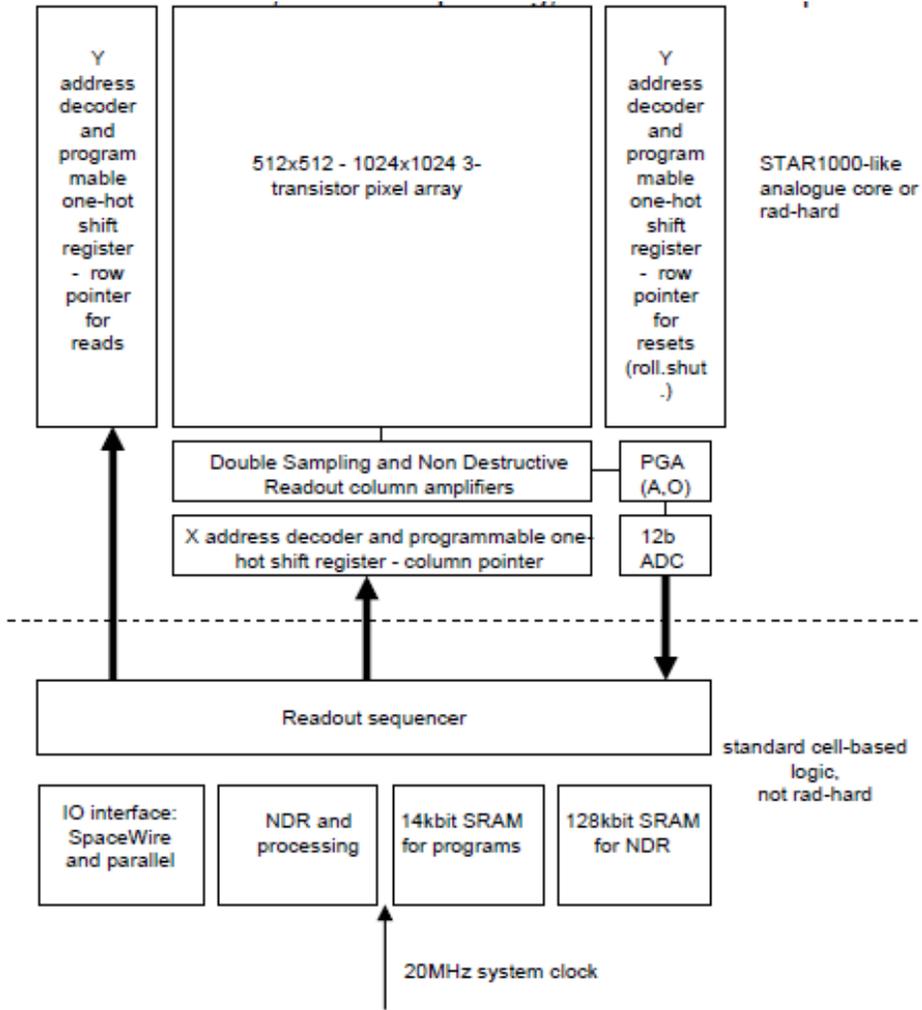
OH Design – Optics



- Aperture 26 mm, F#1.1, Ø20 deg FOV
- Optimized for single stage straylight baffle
 - few lenses
 - large diameter lenses
 - thin lens edges
 - Black coated spacers with light traps
- Pupil at front of optics → smaller baffle
- Aspherical design using only radhard glasses

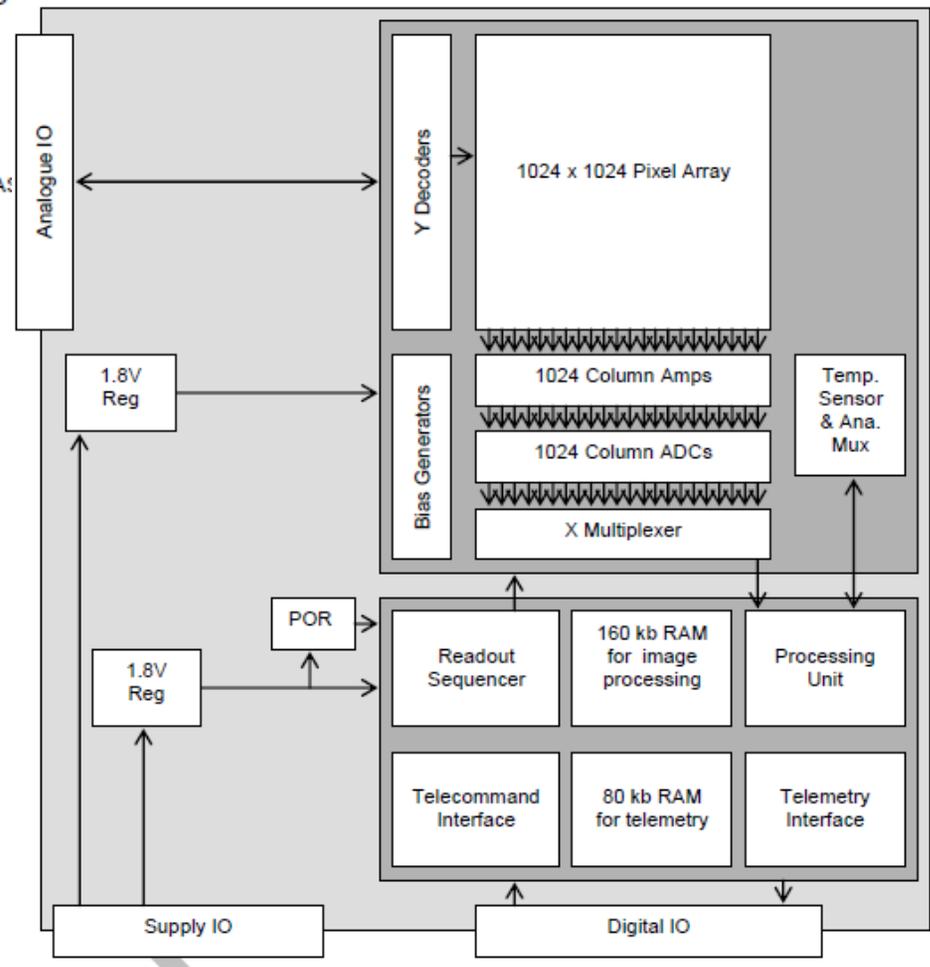


OH Design – LCMS and Faint Star



LCMS, 512x512, 25 μm pixels

STAR1000-like analogue core or HA; rad-hard

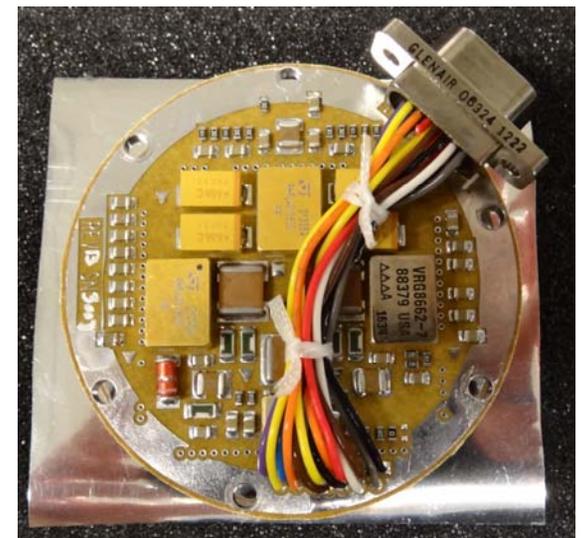
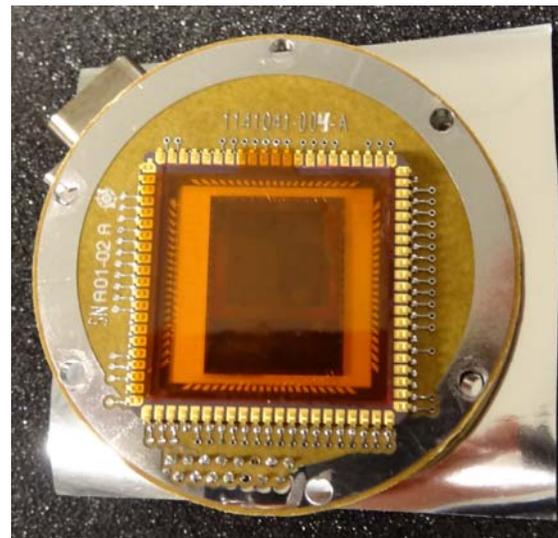
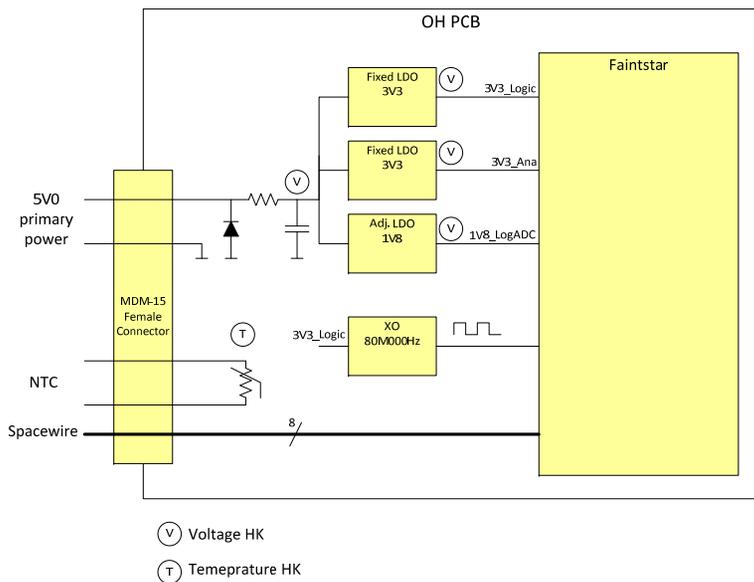


Faint Star, 1024x1024, 10 μm pixels

OH Design – Electronics and PCB



- Identical PCB size and stack-up for LCMS and Faint Star
- Limited EEE components required (voltage regulators, oscillator and decoupling)
- +5V and SpW interface (LCMS 20 MHz, FS 80 MHz)
- Sensor external thermistor added (connected to two unused pins in the MDM connector)



OH Design – Baffle



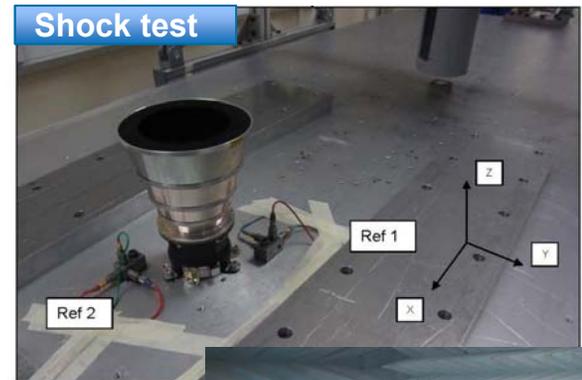
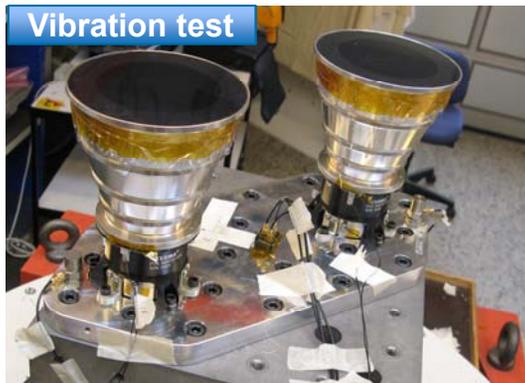
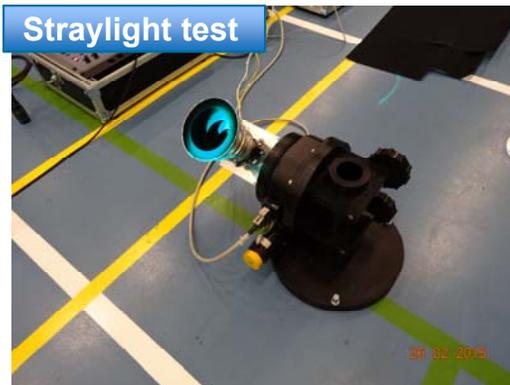
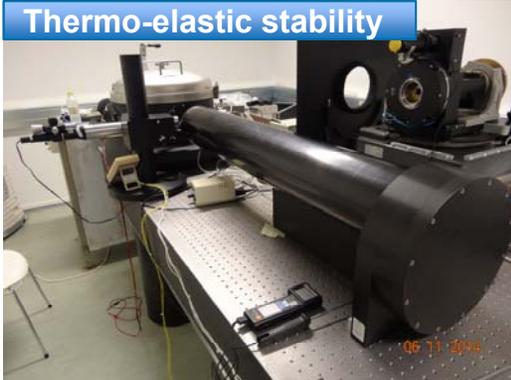
- As small as possible → single stage
- Thermally isolated mount:
 - Minimum heat flow towards camera and satellite interface
 - Less radiative heat from outer baffle towards camera
- Mechanical isolated from camera → less thermo-mechanical disturbance
- Consisting of separate cup-shape sections containing a vane and cone section → faster/cheaper manufacturing, possible to Black coat all internal surfaces.



Sun Exclusion Angle, half cone, [deg]	Baffle Outer Diameter [mm]	OH Total Length [mm]	Baffle Mass [g]
45	99	104	163
35	100	136	190
30	125	165	230
26	155	213	315



STR OH Qualified



Single Star Performance Test



All numbers in arcsec (1 σ)	LCMS OH 176"/pixel	HE-5AS 77"/pixel	FS1 BB 70"/pixel	FS1 EQM 70"/pixel
Residual calibration error	4.1 / 5.0	3.6	2.4	2.1
NEA (mv4)	2.4 / 3.0	0.7	0.7	0.9
NEA (mv5)	4.4 / 5.0	1.1	1.4	1.6
NEA (mv6)	8.5 / 9.5	3.1	2.7	2.8
Chromatic aberration error	2.1 / 3.5	2.0	2.3	2.4
Centroiding error (mv4)	4.1 / 6.1	-	1.0	1.1
Centroiding error (mv5)	5.3 / 8.4	-	1.6	2.0
Centroiding error (mv6)	7.9 / 9.0	3.0	2.0	1.6
RSS divided by $\sqrt{20}$ (all stars mv6)	2.8 / 3.2	1.3	1.1	1.0

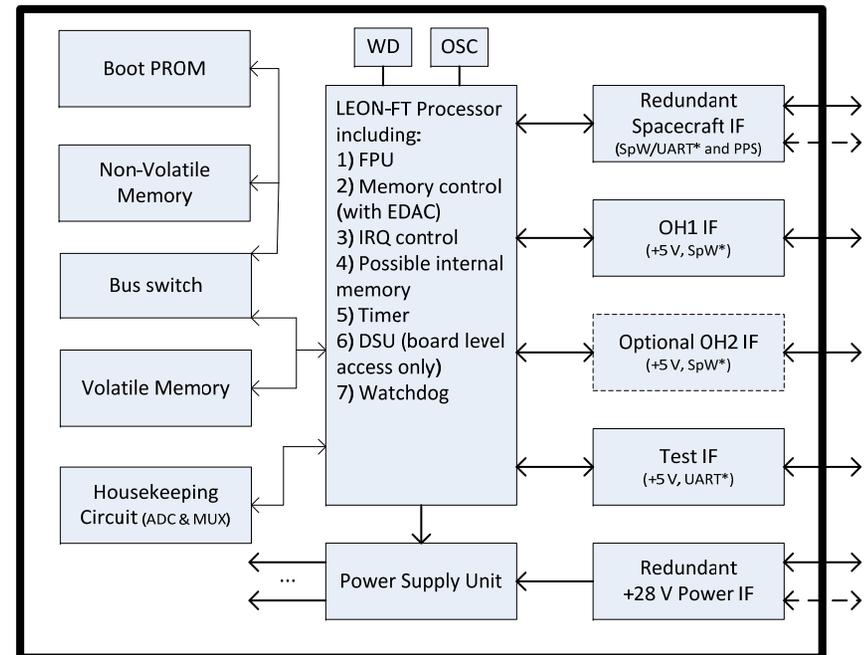
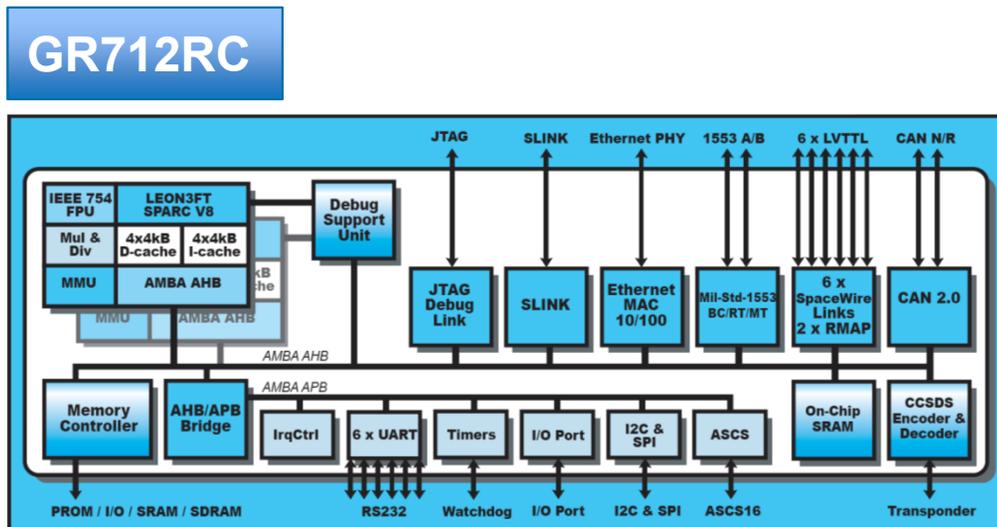
Notes:

- The LCMS values are based on an average/worst case across 12 FM units delivered for F7
- The HE-5AS numbers are taken from the CryoSat-2 budget
- All LCMS results assume FPN and DCNU removal
- All FS1 results are obtained without FPN/DCNU removal
- All measurements have been performed at approx. 25 degC sensor temperature with an image exposure time of 150 ms

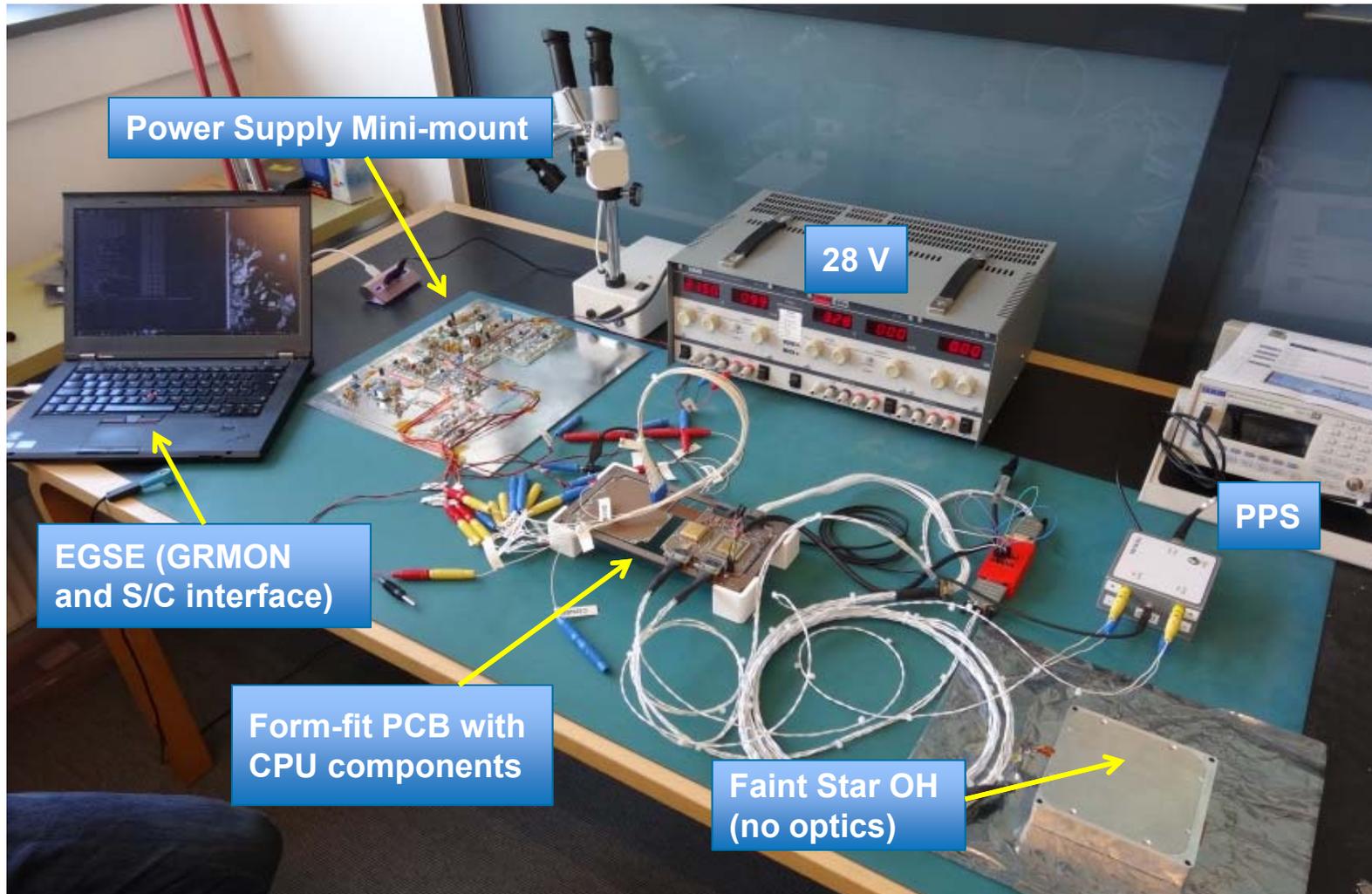
STR EU Overview



- LEON architecture
- Two OH SpW interfaces including +5 V with current limit protection
- Redundant spacecraft interface with synchronization PPS input, based on either SpW or RS-422
- Wireless test interface
- Internal power supply with redundant +28 V (20-36 V) voltage input
- Boot, non-volatile and volatile memories
- Housekeeping circuit for monitoring of voltages, currents and temperatures



STR EU Prototype

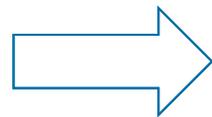


STR EU Prototype Test



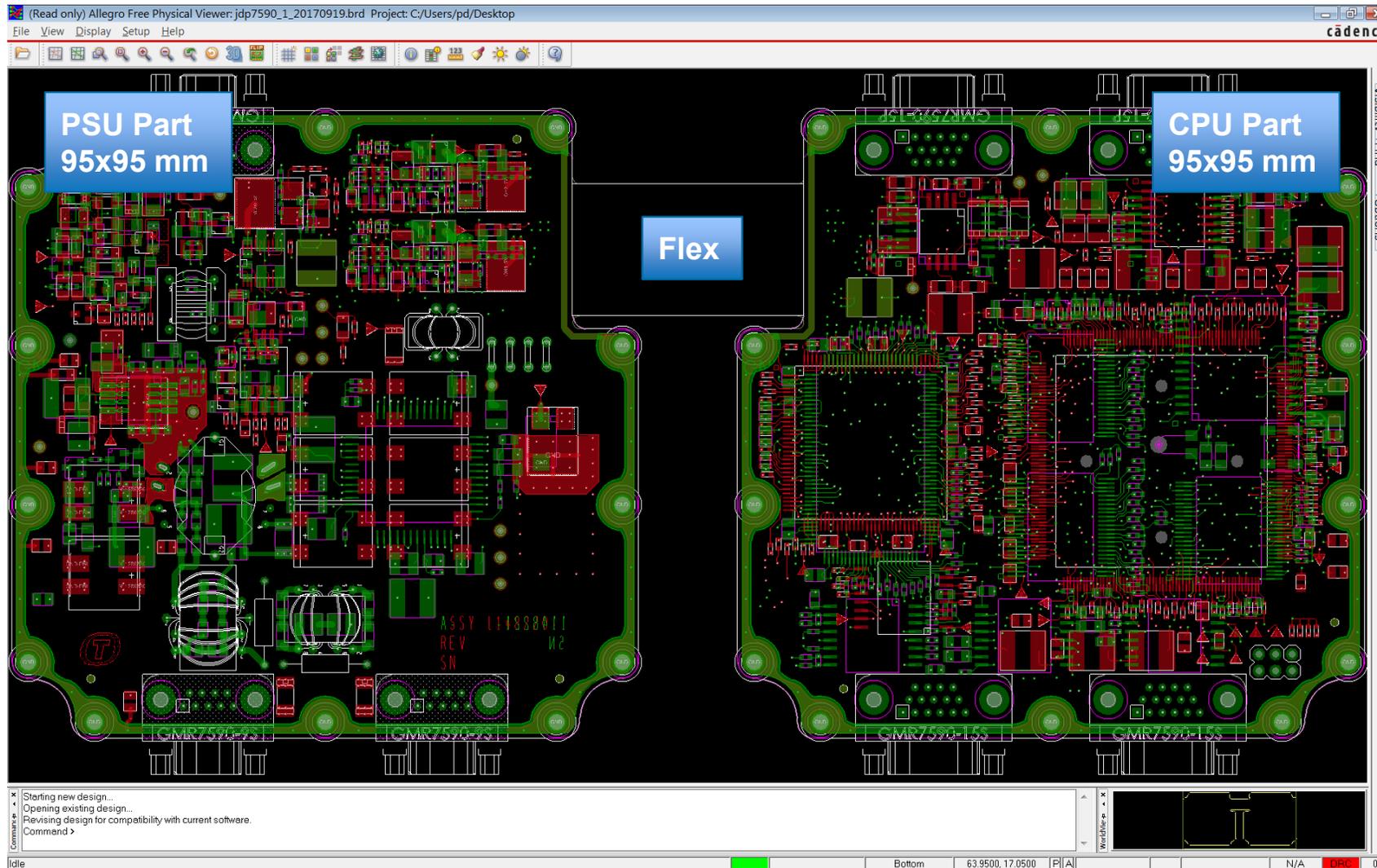
The STR EU Prototype has been functional and performance tested:

- Approx. 3 W average
- 83 Dhrystone MIPS
- Flash and PROM successfully tested including power on/off
- Redundant SpW (10 Mbps) or RS-422 (1 Mbps) Spacecraft interface with PPS successfully tested
- Two OH SpW interfaces (80 Mbps) including +5 V supply voltage with current limit protection successfully tested
- Supervisor and housekeeping circuits successfully tested
- Power supply successfully tested



Ready for EQM manufacturing

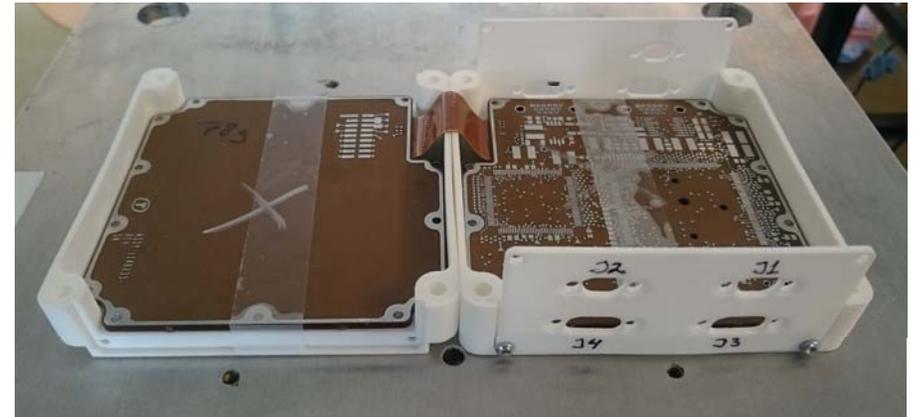
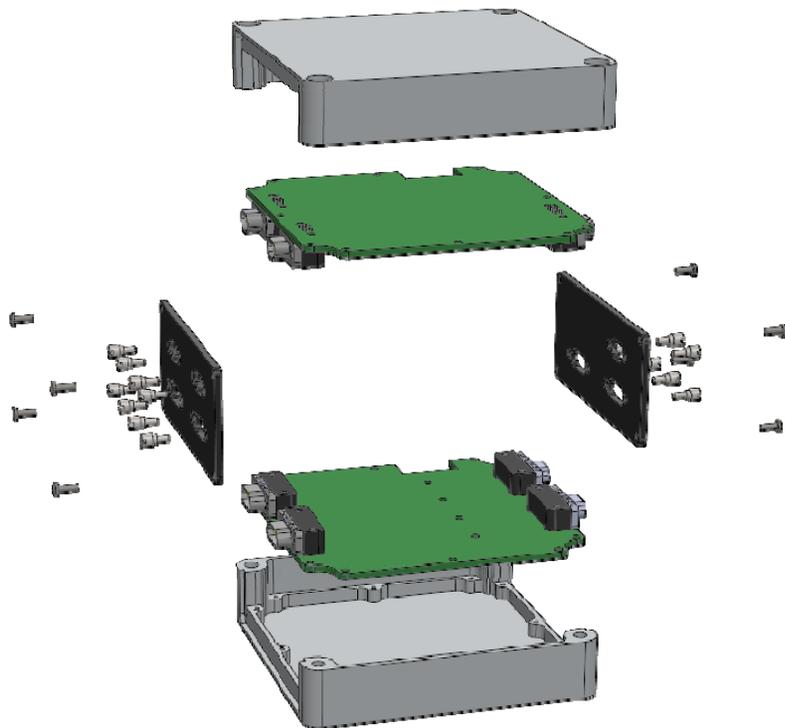
STR EU EQM PCB Layout (in production)



STR EU Box Design

The compact EU properties are:

- Dimension: 100x100x40 mm³
- Mass: 450 g incl. PCB
- 1'st eigenfrequency higher than 600 Hz
- Attaches to S/C using four M4 bolts



STR Software Overview



The star tracker application software main design drivers have been:

- Reuse of heritage algorithms enhanced and verified on-board ESA CryoSat-2
- Robustness, Acquisition and Tracking during heavy radiation storms
- No Active Cooling yet robust EOL Acquisition and Tracking at elevated temperatures
- Modularity and Portability for execution in dedicated EU or hosting on central on-board computer

Star Tracker based on Faint Star predevelopment for Telecoms



Study objectives: The objective of the activity is to derive an optimized Star Tracker design for Telecoms satellites based on the Faint Star detector with the main development focusing on the optimization of Faint Star's use and the STR software in order to provide a low impact, easy hosting of the S/W in the OBC.

Task 1:

The first task includes major trade-off activities required to design an optimum OH capable of operating in GEO for 15 years and high altitude polar LEO for 10 years. The major focus is on the assessment of the Faint Star internal processing capabilities:

- Is it possible to run the star tracker SW on a central LEON based host OBC with the expected resources in terms of memory and processing power?
- To what extent can the Faint Star internal functionality be used and still meet the operational requirements from the primes?

Task 2:

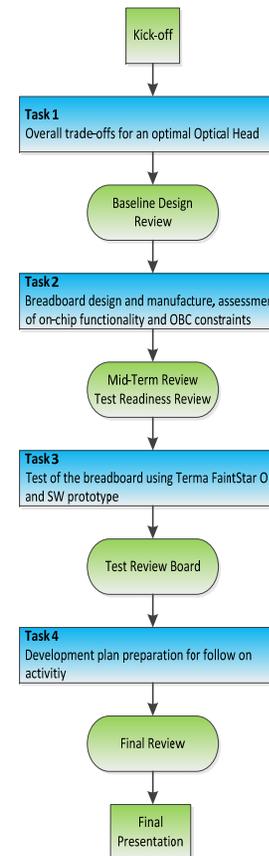
The second task includes both HW and SW activities. The HW part comprises the design and manufacturing of a highly compact OH. The SW part comprises design activities such as OH interface, interface to the OBSW and an implementation of the delta (not covered by the Faint Star detector) star tracker algorithms required for optimal robustness.

Task 3:

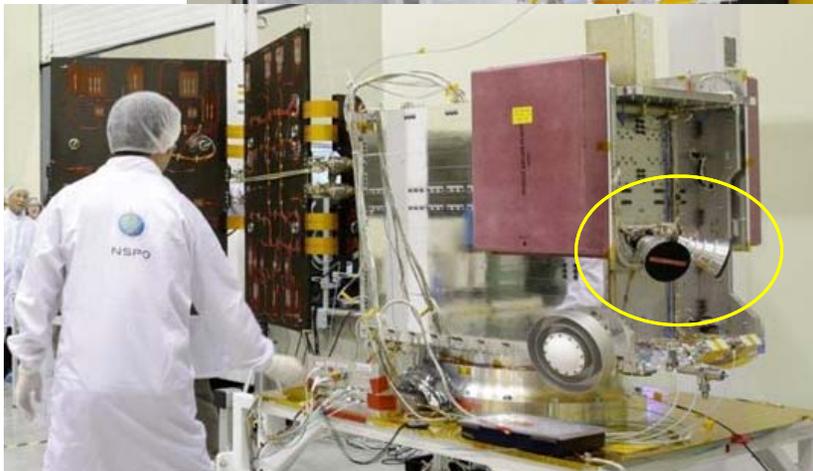
This task comprises test of the manufactured Faint Star based OH together with the SW operated in a real-time environment for verification of the implemented functionalities. A night sky test will also be performed.

Task 4:

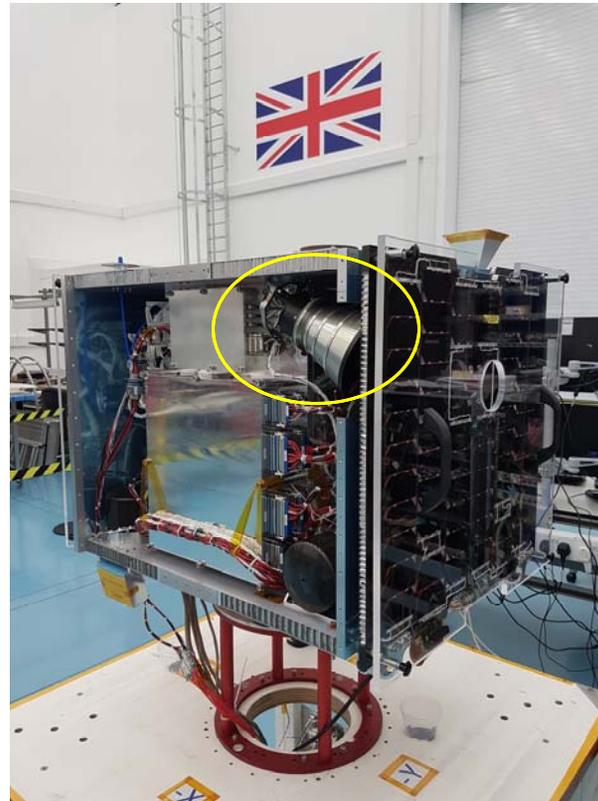
The final task will layout a development plan for follow-on activities including also an OH EEE parts list and testing strategy prior to satellite prime delivery.



Example missions...SSTL FormoSat-7



Example missions...SSTL "Carbonite-2" (Earth-i demo)



Datasheet (1/2)



Optical Head	T1	T2
Accuracy (EOL @ +30 °C, 1 σ)	1.5 arcsec Cross-boresight 9 arcsec Roll-boresight	3.5 arcsec Cross-boresight 21 arcsec Roll-boresight
Power Consumption	0.75 W	0.5 W
Interface CMD/Data	SpaceWire, 80 MHz	SpaceWire, 20 MHz
Maximum Update Rate	10 Hz	5 Hz
APS Resolution	1024 x 1024	512 x 512
Camera Head Mass	310 g	
Optical Head Dimension	Footprint Ø92 mm Height 68 mm	
Straylight Baffle Options (SEA, Dimension, Mass)	45 deg, Ø99 mm, total OH height 104 mm, 163 g 30 deg, Ø125 mm, total OH height 165 mm, 230 g 26 deg, Ø155 mm, total OH height 213 mm, 315 g	
Supply Voltage	5.0 V	
Operating Temperature (full performance)	-40 °C to +30 °C	
Survival Temperature	-45 °C to +70 °C	
Lifetime	12 years in LEO @ 1000km 15 years in GEO	
Lenses	Aspherical, radiation hard glasses	
Field of View	20 deg circular, full moon accepted in FOV	

Datasheet (2/2)



Electronic Unit	
Architecture	LEON3-FT
Dimensions	100 x 100 x 40 mm ³
Mass	450 g
Power	<3 W (average)
Supply Voltage	Redundant +28 V (20 V to 36 V)
Spacecraft Interface (TC/TM)	Redundant SpaceWire or RS422
Camera Head Interfaces	SpaceWire (maximum 2 OHs)
SEU Tolerance worst case GEO flux (25k protons/cm ² /s)	Acquisition & tracking full performance
SAA Tolerance	Acquisition & tracking full performance
Slew Rate	< 0.5 deg/sec full performance < 3.0 deg/sec reduced performance
Acquisition time	< 10 s