SELEX GALILEO

A Finmeccanica Company

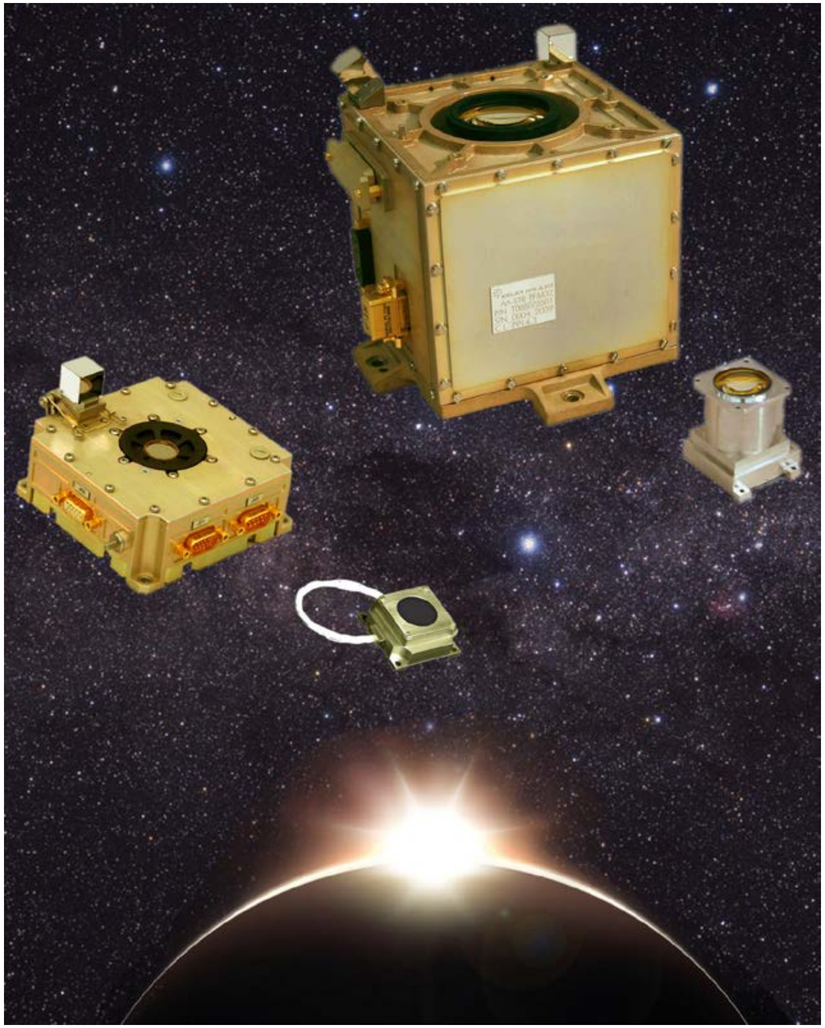
ADCSS 2012

Miniaturization activities and issues for AOCS sensors

Franco Boldrini – Paolo Fidanzati

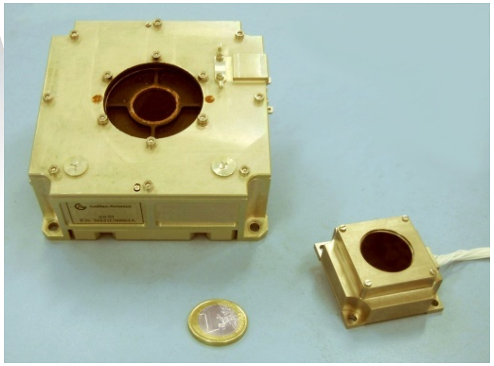
Outline

- SELEX Galileo Miniaturization roadmap for AOCS sensors
- Sun Sensor Miniaturization results
- Star Tracker Miniaturization incremental approach
- Pros & Cons of Miniaturization and Conclusions



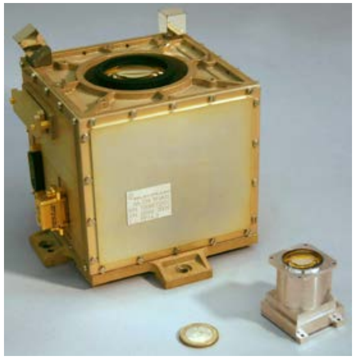
Attitude Sensors Miniaturization Overview

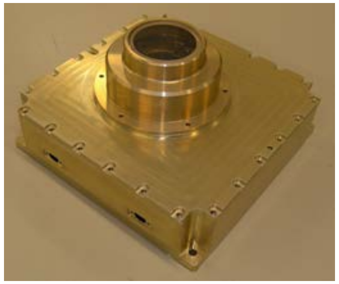
Star sensor, sun sensor and navigation camera have been identified as suitable for a common development aiming to miniaturization.



Modern **Sun sensors** are already two-components' units, with APS and ASIC. The huge amount of signal, the non stringent accuracy requirements and the pinhole concept make the **miniaturization within reach.**

Star sensors miniaturization is challenging and so far limited by technologies availability. Configurations with optical heads & S/C centralized processing used as **intermediate development step**.



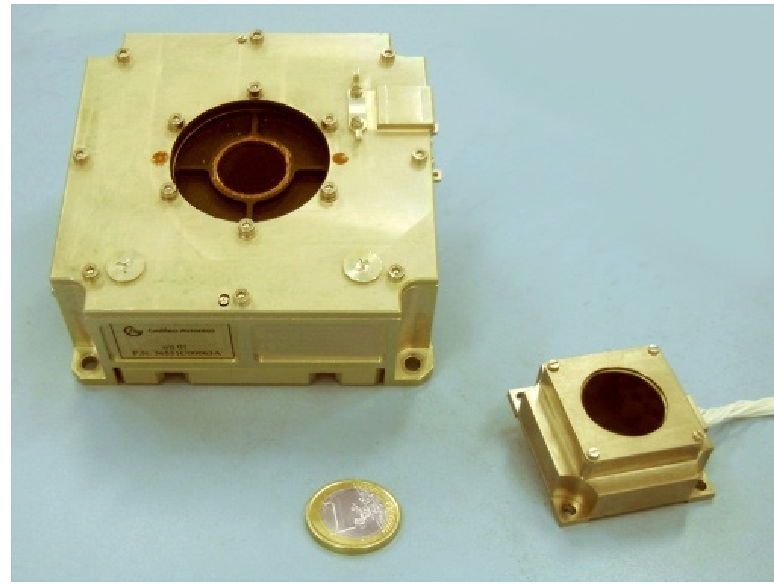


Navigation Cameras miniaturisation depends on needed functionalities, FOV size, scene illumination, etc.
To be directly **derived from the star trackers activities**, with the tailoring of the optics and RAM size.

Sun Sensor on Chip

Current Status:

- First prototypes, already including MEMS technology, tested in 2010 with very promising results.
- Development of an EQM model under ARTES to be started within the year.
- Strong interest from the AOCS users community and flight opportunities offered.



Miniaturization not really an issue from optical / performance point of view

↓

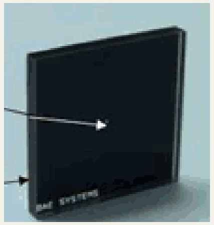
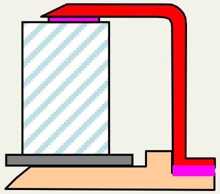
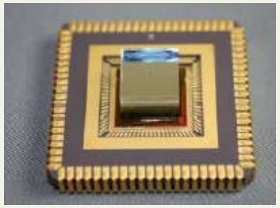
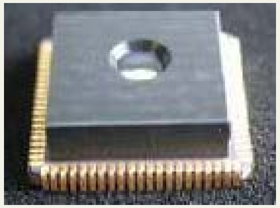
Extra efforts made to further reduce complexity of an already simple concept

Sun Sensor on Chip

Improvement areas investigated, aiming to miniaturization and lowering production costs:

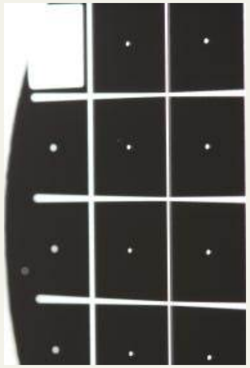
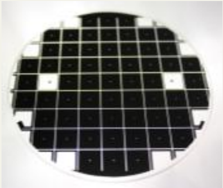
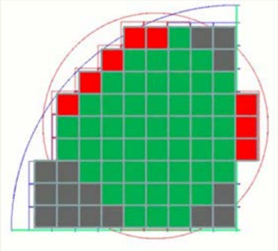
Pinhole integration in the detector package:

- Bonding & sealing method
- Wirebonding Pinhole layer
- Custom (over)size package
- Lid material choice

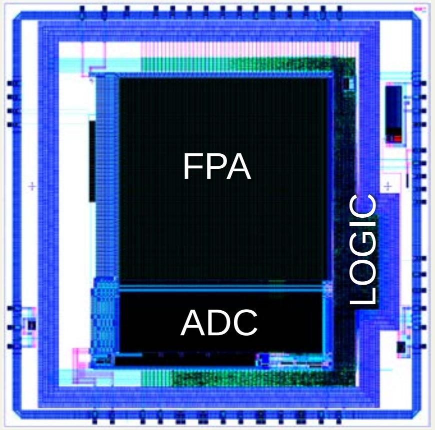
Full wafer scale approach

- Glass wafer over Silicon wafer
- Alignment
- Testability
- Dicing and sawing
- Process yield

Off chip logic and electronics minimization:

- «Smart detector»: pixel array, logic, power supply (5V input), oscillator, I/Fs in one chip
- CMOS Si technology limits
- Radiation hardening
- Low power design



Achieved Solutions:

- **Pinhole integration in the detector package**
  - MEMS stack in fused Silica
  - Pinhole metal layer with no unintentional pinholes
  - Wire bonding optimized for presence of MEMS stack
  - Cover lid and sealing methods to be selected between three options
- **Wafer scale approach**
  - Poor yield combining MEMS optics & Silicon manufacturing processes
    - Wafer scale fabrication of the optical Stacks + AR coating
    - Die to Die Assembly of the CMOS chip and optical stack (incl. alignment)
- **Off chip logic and electronics minimization**
  - First “system on chip prototype” fully working (pixels + logic + SpW I/F)
  - Low power consumption
  - Use of 18µm 2P4M CMOS image sensor + rad hard logic libraries
  - Off chip oscillator
  - Off chip 5V → 3.3V linear regulator

SELEX GALILEO
A Finmeccanica Company

Star Trackers miniaturization constraints

- The star sensor is dominated entirely by the size of its logic and memories, as well as by the process limitation of the rad-hard logic.
- Star tracker optic system is far to be obvious and a MEMS optics bonded on the chip is a very challenging target.
- “on chip” integration of non volatile memories and power DC/DC converter still in early maturity stage.
- Development time and costs for miniaturized star trackers are much higher than sun sensors.
- Customers’ acceptability of deviations from “space rules” (connectors, mechanical I/Fs, etc.) remains uncertain.

The star trackers miniaturization roadmap

2012

2015

New generation APS smart detectors (Faint Star?)

Smart Miniaturized Optical Head (Algorithms executed in AOCS computer)

Lessons learnt

????

Dedicated detector chip with embedded CPU, RAM, NVM

Fully autonomous Star Tracker on Chip

SELEX GALILEO
A Finmeccanica Company

Star Tracker Miniaturization goals

- **Simple design with no active cooling**
  - thermal design become the main issue
- **Reduce number of lenses**
  - poor availability of rad hard glasses from conventional supplier
  - investigation on alternative suppliers (limited heritage) and optics layouts
- **Titanium ←→ Aluminum trade off**
  - Titanium ok for lenses CTE matching
  - Aluminum ok for thermal dissipation
- **Innovative structure materials and lens mounting design to be investigated:**
  - Controlled Expansion Aluminium alloy in answer to CTE mismatch issue
  - Single threaded retaining ring for lens mounting
- **Reduce (or eliminate) focal plane adjustment for focalization, thus reducing costs:**
  - High tolerances required
  - Limit to star detectability

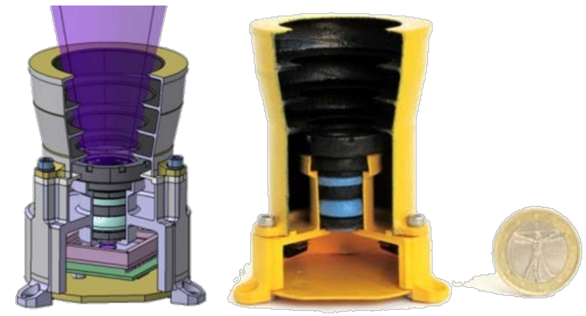
Miniaturized Optical System – First solution

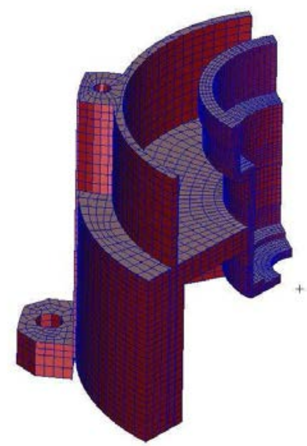
First solution (2011):

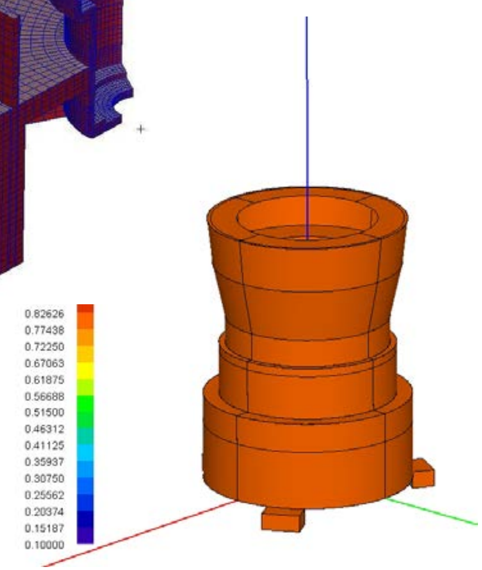
- Innovative use of CE7 material
- Standard rad-hard glasses combined with Fused Silica elements
- Fully passive thermal design
- No on ground focalization needed (goal)

Major issues:

- CE7 use not a viable solution:
  - Limited space heritage
  - Sandvik – Osprey unique supplier
  - Not available as raw material but only as finished parts
- Limited choice of rad hard glasses.
- On ground focalization cannot be totally eliminated without compromising optics performances.







SELEX GALILEO
A Finmeccanica Company

Miniaturized Optical System – Current Status

- **Revised Goal (2012):**
  - design a miniaturized optics suitable for a future smart optical head, passively cooled.
- **Current study results:**
  - Single piece box + lens barrel made in Titanium
  - Use of kapton tape (or similar) to improve thermal behavior
  - Limited (and manageable) detector performance degradation at extreme operating hot cases
  - Not operating cold temperatures could be problematic for survivability: possible use of self heating with unit on: area to be investigated
  - Lens spacers in titanium plus 2 spacers in Aluminum Alloy
  - Use of rad hard lenses + fused silica elements (external lenses)
  - Check other layouts with glasses from alternative suppliers in progress
- **Next steps:**
  - Prototype to be built in 2013 and tested coupled with Sun Sensor on Chip detector

SELEX GALILEO
A Finmeccanica Company

Star Tracker optics alternative layouts trade offs

Proposed solution	Optical performances	Stray light control	Material reliability and performances	Material availability
Inverse Schmidt collimator	GOOD: very wide waveband, easy aberration control BAD: effective f# below acceptable value	BAD: aperture very close to the focal plane	GOOD	GOOD
Alternative rad hard glass supplier standard objective	GOOD: compliance with first order requirements, wide availability in the glass catalogue simplifies the correction of chromatic aberration and thermal defocus	GOOD: the stray light attenuation factor of a usual star tracker is foreseen	BAD: to be verified	BAD: real availability to be well checked
Standard rad hard glass supplier objective	GOOD: compliance with first order requirements, a promising combination of glasses has been found	GOOD: the stray light attenuation factor of a usual star tracker is foreseen	GOOD: proven flight heritage	GOOD: all the selected materials are available at the moment

Miniaturization effects

Equation «small dimensions = low cost» not obviuos at equipment level …

Area	Positive factors	Drawbacks
Design	Less number of «pieces»	Everything gets more difficult
Development	Hard to find any …	Costs extremey high. Difficult ROI due to low FMs unitary cost
Small size	Handling, managing, moving and storing small objects is easier	Production costs not linearly scale with dimensions Tolerances and physical constraints for small dimensions
AIT	Some steps can be parallelized (Vibrations, TVC)	Significant FMs orders needed to support production & testing in batches
Smart detectors	Single piece of silicon with detector and logic (even optics in sun sensors)	Detector becomes a key cost driver. Still need off chip components (power I/P, RS422 drivers, NVM …)

For suppliers, attitude sensors' cost does not go by grams!