ESA STR developments in the recent past and present, main achievements and future developments

Steeve Kowaltschek (ESA/ESTEC – TEC-SAA)

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Late 1990, autonomy reaches Star Trackers devices

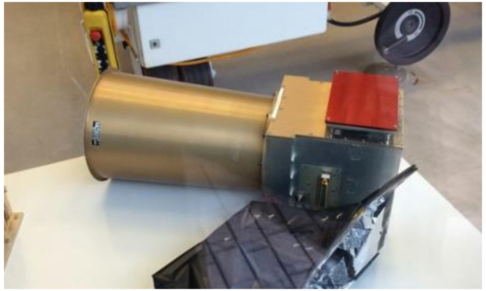
First "Star Trackers" were single-star,

The improvement in CCD technology enabled to track multiple stars at a time, thus enabling an information of the rotation around the line of sight of one single equipment. Late 1990, the increase in CPU power and memory available for space Star Trackers enabled to add a new functionality : the autonomous attitude determination and Tracking.

From that time, Europe started to lead the world in this field, with few companies :

- **DTU** (Technical University of Denmark) : First autonomous European STR on Proba-1, October 2001
- **Sodern** : SED16 on SPOT 5 (May 2002)
- **Officine Galileo** (Now Leonardo) : Autonomous STR on Mars Express (June 2003) and Rosetta (March 2004)
- **Jena Optronik** : First launch of ASTRO-15 in 2003
- **Terma** : First launch of NRL MiTEx in 2006 (GEO orbit)

DTU ASC (Advanced Stellar Compass)



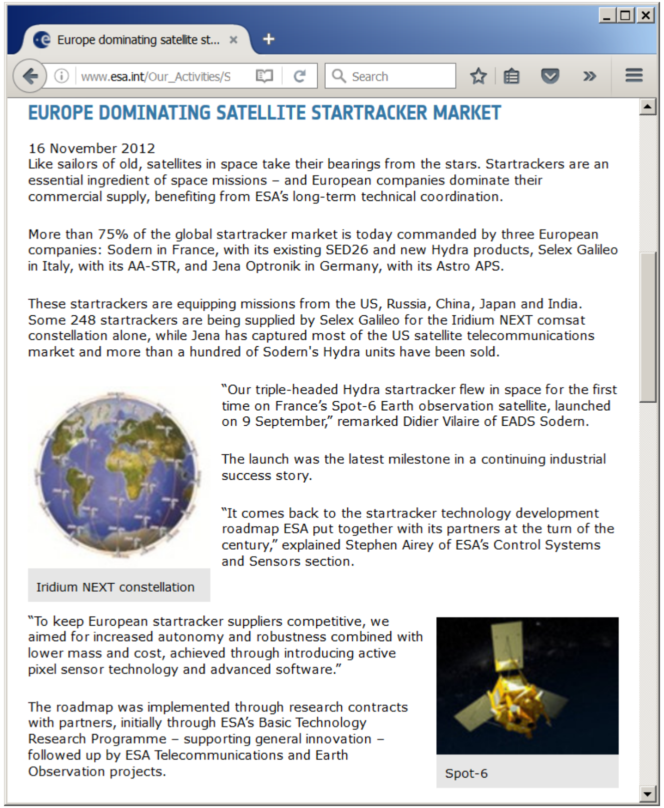
Officine Galileo
Rosetta (5.2 kg Optical Head)

Commercial success and state of the art

Hundreds of European Star Trackers have been sold throughout the world from the early 2000s,

But this first generation of Star Trackers could still be improved on many areas :

- Improvement of **Straylight** rejections to ease accommodation,
- Capability to **withstand** larger level of **detector degradation** (radiation damage)
- Capability to **operate** in all modes with **large fluxes of particles** (solar events of in radiation belts)
- Improvement of sky coverage, guaranteeing lost-in-space acquisition in 4π steradian
- Capability to operate with the **moon in the Field of View**
- Quicker update rate (2 to 10 Hz)
- Capability to be robust to **larger angular rates**
- **Reduction of volume, mass, and power consumption**



EUROPE DOMINATING SATELLITE STARTRACKER MARKET

16 November 2012
Like sailors of old, satellites in space take their bearings from the stars. Startrackers are an essential ingredient of space missions – and European companies dominate their commercial supply, benefiting from ESA's long-term technical coordination.

More than 75% of the global startracker market is today commanded by three European companies: Sodern in France, with its existing SED26 and new Hydra products, Selex Galileo in Italy, with its AA-STR, and Jena Optronik in Germany, with its Astro APS.

These startrackers are equipping missions from the US, Russia, China, Japan and India. Some 248 startrackers are being supplied by Selex Galileo for the Iridium NEXT comsat constellation alone, while Jena has captured most of the US satellite telecommunications market and more than a hundred of Sodern's Hydra units have been sold.

Iridium NEXT constellation

"Our triple-headed Hydra startracker flew in space for the first time on France's Spot-6 Earth observation satellite, launched on 9 September," remarked Didier Vilaire of EADS Sodern.

The launch was the latest milestone in a continuing industrial success story.

"It comes back to the startracker technology development roadmap ESA put together with its partners at the turn of the century," explained Stephen Airey of ESA's Control Systems and Sensors section.

"To keep European startracker suppliers competitive, we aimed for increased autonomy and robustness combined with lower mass and cost, achieved through introducing active pixel sensor technology and advanced software."

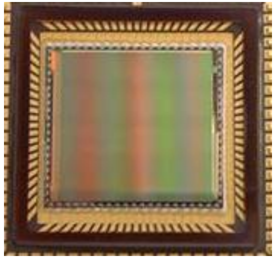
The roadmap was implemented through research contracts with partners, initially through ESA's Basic Technology Research Programme – supporting general innovation – followed up by ESA Telecommunications and Earth Observation projects.

Spot-6

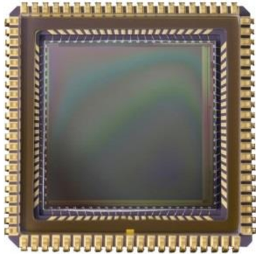
2000s, introduction of APS detectors

At this time, the CMOS (APS for Active Pixel Sensor) technology became more popular for terrestrial applications, and many aspects were of interest for Star trackers :

- Direct pixel access (region of interest or windowing)
- Fast readout time
- Reduced degradation due to radiation (no problem of Charge Transfer Efficiency)
- Anti blooming capabilities
- Reduction of surrounding electronics needed (ADC present on the chip and digital outputs)



STAR1000 APS Detector



HAS2 APS Detector

TEC-SAA (AOCS & Pointing Systems section) identified this technology for Star Trackers and proposed to engage development of standard products (STAR1000, HAS), with ESCC evaluation.

Belgian delegation has supported these initiatives, financing developments :

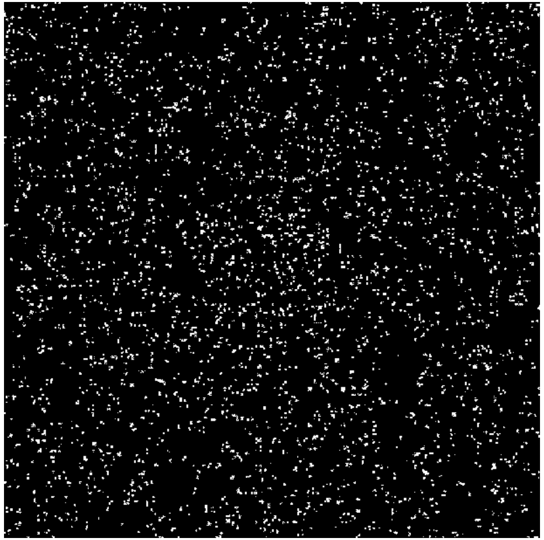
- At **IMEC** (before 1999),
- At **Fillfactory** (further named **Cypress** and **On Semi**)
- At **CMOSIS** (now AMS group) since 2011.

Key element : Availability or Robustness

The first generation of CCD Star Trackers was able to determine its lost in space attitude with a very limited amount (around 10) of particles (protons) per image.

- Typical figures (100 ms int, 20 mm shielding, 1 cm^2 detector area) :
    - GEO "quiet" conditions : 0 to 1 p+ per image
    - LEO 800 km "average" conditions (in the belts) : around 10 p+ per image
    - GEO solar flare (October 1989 5-mn peak) : around **2000** p+ per image

- Most of the efforts engaged in the 2000-2010 period were focussed on the capability to acquire during solar flare conditions, originally driven by the availability requirement of a telecommunication satellite when STR is the main (or only) AOCS sensor.
    - The need is even higher when the STR is meant to be operated in critical phases of missions (interplanetary / orbit insertion)
    - SW of CCD-based STR were improved starting in 2005, while the first generation of APS-based STR with improved electronics (CPU, memory) have eventually reached full robustness (sometimes with margin)



Worst Case STR image including radiation degradation and SEUs Naked eye does not recognize stars

Today, the APS-Star Trackers produced in Europe for the High Reliability market are able to perform this transition during worst case conditions in a few seconds.

Star Trackers remain complex devices

As seen in the previous slides, Star Trackers have seen tremendous improvements in the last decade, mostly in Europe who is supplying 75% of the world needs for high reliability applications.

But Star Trackers have to be used with care, in particular when designing a new platform,

- Understanding of the (numerous) reference frames between supplier and prime is vital
- Star Trackers are more sensitive to the external environment than other sensors (Gyros), mostly because they are optical equipments :
    - Sensitive to highly energetic particles,
    - Sensitive to pollution,
    - Sensitive to other satellites or objects in a field of view,
    - In very specific missions (Rosetta), sensitive to dust
    - Sensitive to parasitic light coming from celestial bodies or reflected by the S/C itself,
    - Extremely sensitive to temperature (radiation induced degradation of a detector – creating spikes or non uniformity - doubles every 6 degrees C).

in short, **handle with care**, should the STR be used for Normal Modes, even more when used in timely critical operations or survival modes.

Supporting the users

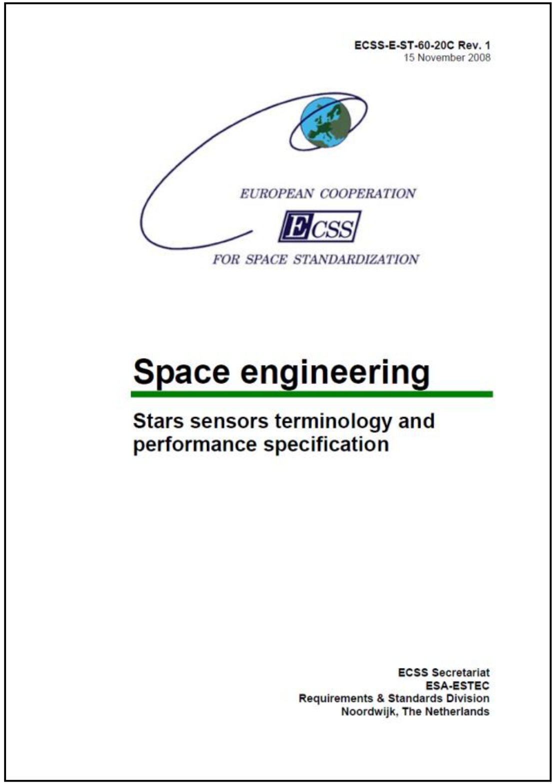
In 2008, was issued the first "**Stars sensors terminology and performance specification**" (ECSS-E-ST-60-20C)

The standard has helped many users to correctly specify their needs, using terms defined in the standard. It also helped to understand the different contributors to the performances at detector or optical level.

A new revision has been prepared with key additions :

- Introduction of an Annex integrating **core data and commands** (originally prepared in the frame of SAVOIR-SAFI WG),
- Focus on the way to specify robustness and performance requirements against environmental effects, for instance **solar flares**,
- Alignment of the performance metrics with the **ESA Pointing Error Engineering Handbook**

A working group will implement the comments from the Public Review. Convenor is **Pierre-Emmanuel Martinez** from CNES


ECSS-E-ST-60-20C Rev. 1
15 November 2008

EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

Space engineering

Stars sensors terminology and performance specification

ECSS Secretariat
ESA-ESTEC
Requirements & Standards Division
Noordwijk, The Netherlands

Parallel initiatives

ESA has been mostly involved in the development of “stand-alone” Star Trackers, should it be based on a single piece (AA-STR, ASTRO APS) or segregated between Optical Head and Electrical Unit (Terma, Sodern Hydra).

Recent (or not so) evolutions in the area of new space and large constellations have introduced new concepts :

- Many initiatives in the world (small companies or universities) to develop miniaturized STRs for the growing cubesat market, both on the hardware and the algorithmic side,
- Large use of COTS while trying to maintain availability (example of OneWeb),
- Resources sharing with the rest of the platform embedding STR SW in the On Board Computer’s CPU and memories

A Star Tracker for cubesats that can be bought online from China

Sodern Auriga Optical Head for OneWeb

« Lost In Space » by Kelvins - ESA's Advanced Concepts Competition Website

European Star Trackers Overview 2001>2013

2001

Suppliers:
Too many suppliers

State of the art:
Expensive CCD based STR with basic lost in space

Market:
Small but growing market

Proposed Plan:
APS detectors (HAS)
APS STR Developments
Multiple head STR
Robust algorithms

2005

Suppliers:
Reduced to 5 main players

State of the art:
Improved robustness CCD STR
APS STR prototypes

Market:
Expanding into Telecoms

Proposed Plan:
APS STR qualification

2009

Suppliers:
3 Main APS STR suppliers
Europe No.1 worldwide
RoW starting to invest

State of the art:
Robust APS based STR at competitive prices

Market:
Most missions baselining STRs.

Proposed Plan:
Start technology development for next generation

2013

Suppliers:
Significant investment in RoW

State of the art:
Multiple configurations of APS STR. Significant in-orbit experience

Market:
Growing competition from China, USA and India

Proposed Plan:
Qualify next gen detectors
Backthinning
Start next gen APS STRs

Preparing the new generation of detectors

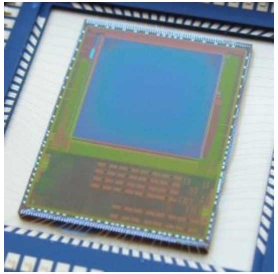
Since 2011, ESA has engaged the development of new radiation hardened detectors to support the next generation of Star Trackers.

The stock of On Semi **HAS2** is very significant and while no more production of the silicon is possible, the supply for STR applications is not a concern.

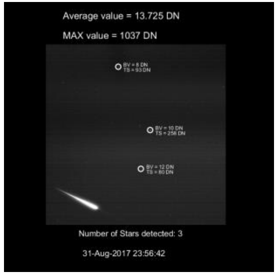
Two detectors are currently being developed :

- On Semi **HAS3**, 1280x1280 global and rolling shutter APS
- AMS (former CMOSIS) **Faint Star**, 1024x1024 rolling shutter APS integrating pixel pre-processing up to centroid calculation. It is also possible to use Faint Star's raw images and keep the "in-house" processing.

Both devices have functioning prototypes, currently being tested and used by STR manufacturers. FMs in 2018



Faint Star first silicon



Meteor caught during Night Sky Test in ESTEC (Faint Star characterization)

Importance to prepare the 3rd generation : CMOS foundries are evolving quickly. Smaller processes below 0.18 um are becoming standard for high-end imaging. The radiation sensitivity (degradation) of these nodes could give promising results, enabling to work without cooling into very harsh environments.

Preparing the new generation of Star Trackers (1/2)

The second generation of High Reliability Star Tracker based on APS detector is currently being engaged (using mostly GSTP and ARTES). Key objectives are :

- Maintain Europe's lead on this strategic market
- Improve competitiveness
- Manage obsolescence
- Keep or improve performance and robustness

	Autonomous CCD	Autonomous APS	2nd generation APS
Development started	1990s	2001	2016
TRL9	2001	2009 (demo) 2012 (in the loop)	2019 / 2020 ?
Mass	> 3.5 kg	2 to 2.5 kg	Less than 2 kg
Power	Up to 20 W	7 to 10 W	Less than 5 W
Detector temperature needed for performance (GEO)	- 10 degrees C	15 degrees C	> 30 degrees or above C
Operation with Moon in FoV	No or Partial	Yes	Yes
Reliability (30 degC, Class 1 EEE)	1000-1500 FITs	≈ 600-800 FITs	≈ 400-500 FITs
Lost in Space during solar flare	No > Then partial	Yes	Yes
Cost	€€€	€€	€

Preparing the new generation of Star Trackers (2/2)

Complementing the established family of STRs, with wide use on all platforms, mission specific requirements are requiring niche products :

- **Very Harsh Environment** : The JUICE mission has required several pre-developments to enable to use of a STR on the mission.
    - Procurement awarded to Sodern (F) involving HW and SW modifications to withstand the environment.

- **Very High Accuracy** : some missions with no possible Fine Guidance Sensor (no payload in the VIS range for instance) require higher performance than the one offered today by the existing or next generation of STR.
    - Activity proposed in the frame of the 2013 Harmonization (ESA specification)
    - A specific development has been engaged with the Core Science Technology Programme.
    - The target is to The objective of to provide a Star Tracker approximately an order of magnitude better on all metrics compared to the existing generation. (0.1 arcsec)
    - Take benefit of the GAIA star catalog, innovative optics
    - This new development would support VHR optical satellites and future Science missions when payload cannot easily be used in the AOCS control loop.
    - Activity running at Jena Optronik (DE)

It is now to give the floor to
the European Star Trackers manufacturers