APPLICATION FOR APERTURE SYNTHESIS TECHNIQUES FOR IMAGING IN EARTH OBSERVATION AND SCIENCE.

Abstract of Thales Alenia Space study for ESA in the frame of ESA contract n°20663/07/NL/HE

1. INTRODUCTION

Thales Alenia Space has led for ESA a 12-month study dedicated to “Applications for aperture Synthesis Techniques for Imaging in Eath Observation and Science”.
The main objective of this study was to provide ESA with a clear status on the interest, capabilities and limitations of the use of Optical Aperture Synthesis Techniques for Earth Observations at high resolutions from Geostationary orbit.

Having identified several key and promising applications, the study was completed by the proposition of an adapted instrument conceptual design and identification of technological development needs.

1.1 High Orbits interests for Earth observation

High orbits (e.g. Geostationary or Geosynchronous) exhibit advantages in terms of Earth observation hardly reachable from low orbits. Major interests come from the ability to :

– observe a zone in permanence or with a very high repeat cycle (for detection of changes, motion follow-on…),
– access rapidly to a zone of interest when needed. Moreover, the size of the interesting zone can also be adapted to the need by mosaïcing several successive acquisitions,
– permanently communicate with on-ground station (for programmation or down-link of image telemesures in a short delay).

Today only Meteorological missions use Earth observations from GEO in particular to reach high repeat cycle (typically about 4 per hour). In this case, the required ground sampling distance (GSD) deals with a few hundred meters.

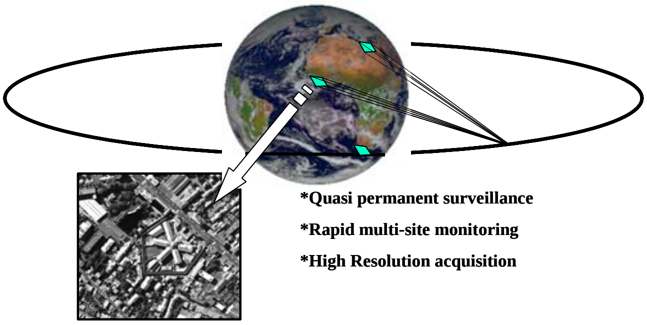

Figure 1.1-1 Advantages of GEO orbit for Earth Observation

These orbital advantages when coupled to high spatial resolution imaging capacities could allow the development of interesting applications in fields of Earth watching and civil security as underlines in this study. For these applications, a high resolution in the order of a few meter is required.

When considering Earth Observation (EO) at high resolution from GEO, classical monolithic telescopes can hardly be envisaged due to the large required diameter (typically several meters) not compatible with current developments, launchers and classical architectures.

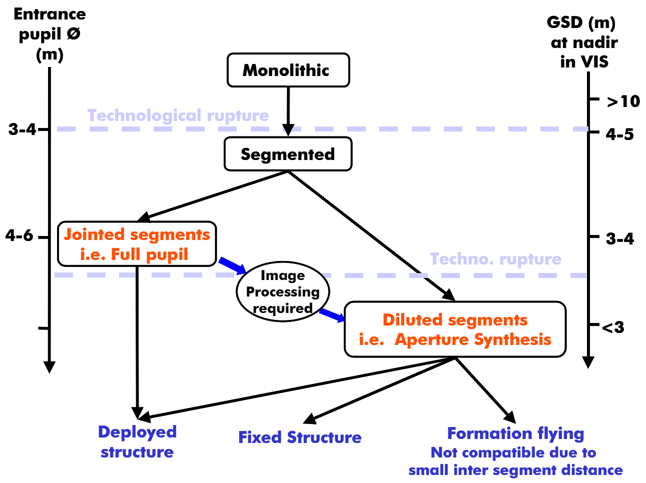

Figure 1.1-2: Possible telescope architectures with respect to pupil diameter and Ground Sampling Distance in case of EO from GEO in the visible spectral domain. Only Aperture Synthesis access to metric GSD range from GEO

The use of segmented and deployable mirrors allows telescopes of diameters up to 5-6 m (for instance, JWST telescope diameter is 6 m). For this full pupil solution, distance between primary and secondary mirrors as well as mass and complex deployments are constraining the access to upper diameters.

For improving resolution from this orbit and access such missions in the future, Optical Aperture Synthesis (OAS), applied to extended source imagery, is identified as a serious candidate. This technique allows to reconstitute a telescope aperture of large surface by co-phasing several individual telescopes of smaller size.

2. STUDY ORGANISATION

2.1 Team Structure

The study team led by Thales Alenia Space as Prime Contractor, has relied on :

- 5 years of R&D activities in TASF on Aperture Synthesis system technology and sizing tools
- The technological expertise of ONERA and XLIM Research groups
- VITO and CLS high-skilled companies, with longstanding experience in the fields of activities involved in the present Study.

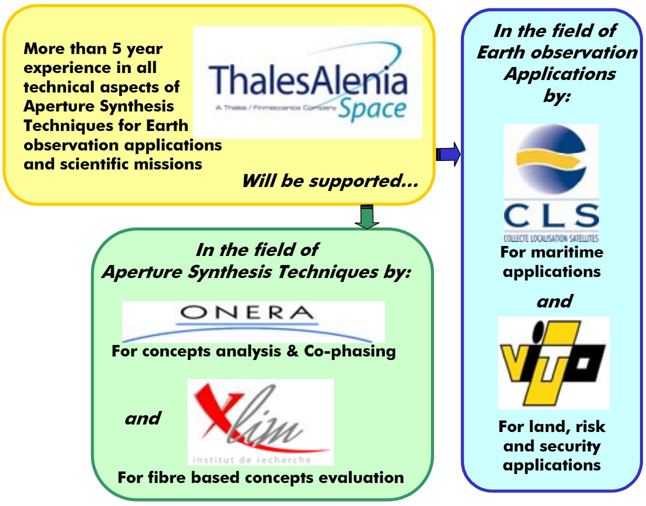

Figure 2.1-1: Responsibilities were shared according to the excellence filed of each team member.

Within this objective, three complementary phases are proposed in this study:

- assess the potential of Aperture Synthesis techniques for high spatial resolution imaging of Earth from GEO.
- identify promising applications of optical Earth observation from high orbits at high spatial resolution
- propose a concept of Aperture Synthesis system allowing to fulfill imaging and mission requirements as derived from identified key applications

3. MAIN STUDY OUTPUTS

3.1 OAS literature survey and technology evaluation

This study has underlined that the most appropriate OAS concepts for Earth Observation mission at high spatial resolution from GEO rely on direct imaging interferometers with dense pupil array. These interferometers are selected in order to provide a full coverage of the frequency plane. This choice is illustrated through the reporting of other concepts already published in the literature.

In first approximation, Fizeau type interferometers are favored wrt to Michelson ones as less complex and more performing for wide field imaging of extended sources.

Circular and linear aperture configurations are retained. Depending on the mission characteristics one or the other could be most appropriate. It has been determined that linear type configuration could be retained in case of foreseen nadir GSD lower than 2m. Indeed, linear configuration is judged more complex due to the required system rotation during the acquisition phase and thus limited to case where a 2 D aperture configuration size is prohibitive.

The number, position and size of aperture sub-pupils depend on the foreseen mission characteristics. The optimization of the aperture configuration has thus be done taking into account the design drivers, the needed mission characteristics and the associated performance.

The methodology developed by TAS-F to size this kind of system as well as the main design drivers and technological characteristics (e.g. co-phasing system and line of sight stabilization system) have also been described, illustrated and presented to ESA.

In particular, an image chain simulation tool devoted to direct imaging interferometry has been developed by Thales Alenia Space allowing simulation of :

- OAS raw image from source image and instrumental parameters
- Image processing and comparison to source image

Based on these tools, an analysis has been conducted to determine the capability range of OAS concepts in terms of imaging characteristics and performance.
The GSD is for instance ranging from 1 to 7 m at nadir in PAN and is directly limited by the telescope baseline dimension. The corresponding FOV capability is also derived, both are determined for spectral domains from VIS to TIR.

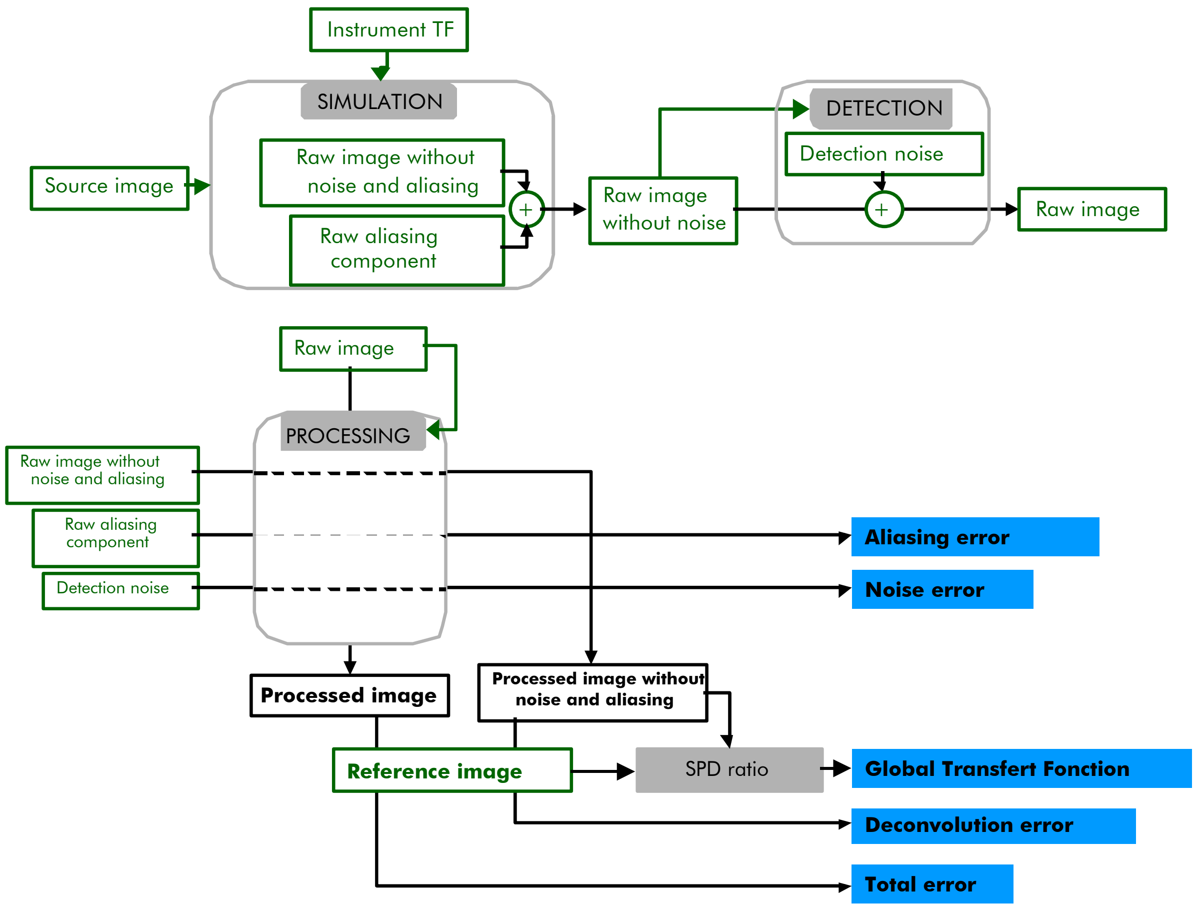

Figure 3.1-1: Principle of Image Chain simulation

3.2 Applications of OAS in Earth Observation from GEO

Through this work, a lot of interesting applications have been identified with a high temporal need and a ground sampling distance lower than 10 m (in VIS). All these applications have been described in detail from a user point of view then from mission requirement point of view.

Among them, **key applications** that justify the need of an OAS mission in geosynchronous orbit have been highlighted. These applications require on demand images to be delivered in near real time mainly to deliver products of :

- fast damage assessment or rapid mapping
- event monitoring
- fast delivery of change detection

The corresponding applications are mainly related to disaster and crisis management, to surveillance of dedicated areas and to security purposes.
The natural disasters, the maritime security and the industrial hazard applications are the most promising ones.
All these key applications exhibit common image and mission characteristics that have allowed deriving the corresponding OAS system requirements.
It is established that an optical system providing following characteristics is compatible of the foreseen mission.

Table 3.2-1: Required Imaging System characteristics

Kind of observatory	**Imager**
Required spectral domains	**PAN + multispectral bands RGB +1NIR 1 broad band in MIR 1 broad band in TIR**
GSD	**<2-3> m at nadir in PAN spectral domain**
Observation strategy	**On demand acquisition in near real time over all the accessible area**

Refinement of the need in terms of geolocation, SNR and Image quality level has been done to size the concept of the corresponding optical system.

It has also been underlined during this second part of the study that this kind of system if used in conjunction with other data sources could greatly benefit to numerous other applications called **promising applications**. Indeed, this second category of applications do not justify the need of an OAS system but could be significantly improved by using images of such a system. These applications are thus potentially "client" of an OAS mission, and this, without adding any technical complexity at the space segment level. Moreover these promising applications claim for on demand acquisitions as well as monitoring or routine observations thus allowing to feed the mission plan of such a system. These applications mainly deal with pollution detection and monitoring, security and sustainability as well as with resource and facilities management.

3.3 Aperture Synthesis Conceptual design

The optical system requirements have been derived from imaging and mission requirements. A GSD of 2m with a Field of view of 60km by 60km are retained for the PAN band. The level of image quality required for the proposed concept is fixed through an image photo-interpretation exercise in line with the selected key application needs. Simulated images with corresponding characteristics are presented hereafter.

Figure 3.3-1: Illustration of images obtained with selected Image Quality objectives (IQ=4 and specified GSD at Nadir (2m))

The conceptual design phase has shown that an instrument concept based on Optical Aperture Synthesis can be envisaged for a 2 m class Earth Observation mission from a geostationary orbit.

The proposed concept is a Fizeau based interferometer those aperture is composed of 6 entrance sub-pupils of 2m diameter each. These sub-pupils are located on a circular base of overall diameter of 7m. The Fizeau configuration is a 3-mirror Korsch configuration where each sub-pupil is a segment of the primary mirror.
Strategies of fine alignment of the interferometer and of line of sight stabilization are discussed regarding the optical performance requirement. The concept proposed for the co-phasing of the interferometer relies on the phase diversity for the measurement and on active optics for the correction (including a deformable mirror in the exit pupil).

The corresponding focal plane architecture relies on 2D detector arrays for all the considered wavelengths (that there are spectrally separated in the optical layout).

To implement this optical concept, a mechanical concept is proposed detailing in particular the deployment strategy of the optical system (as cannot be stowed under fairing as it), deployments are foreseen for each of the entrance sub-pupils and for the proposed baffling concepts.

The need in terms of mechanisms of this kind of system is addressed for the deployments as well as for the optical layout fine positioning thus allowing to propose a control logic from the in-orbit injection to the fine stabilization during acquisition, in accordance with the mission requirements.

However the complete validation of such a concept requires complementary studies and the initiation of technological developments.

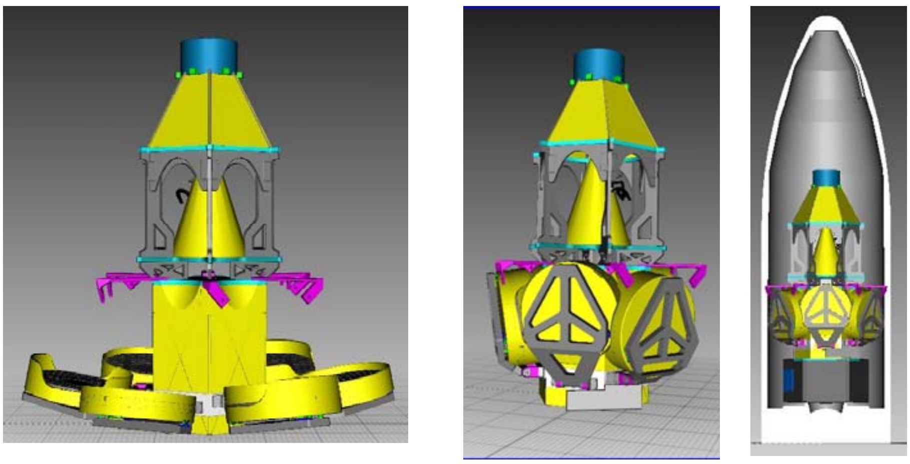

Figure 3.3-2: OAS instrument proposed design

Main complementary studies identified during the conceptual design phase are listed hereafter:

Consolidation of the instrumental concept with more detailed analysis:

- Thermal analyses and short term µ-vibrations
- Thermal architecture concept
- Choice of the location of the pointing and WFE sensors
- Deployment and control mechanisms
- Performance consolidation

Co-phasing:

- Phase diversity optimization
- Line of sight stabilization, impact of the µ-vibrations

AIT:

- Methodology and associated means

And associated identified required technological developments:

Optics

- Deformable mirror adapted to the needs
- Large mirrors manufacturing
- Manufacturing means compatible with the specified WFE

Mechanical and thermal architecture

- Baffle concept
- Deployment mechanisms and fine positioning systems
- Laser metrology

Co-phasing

Breadboard dedicated to the validation of co-phasing concept with high number of pupils.

3.4 Conclusion

During this study, Thales Alenia Space has established a status on the interest, capabilities and limitations of the use of Optical Aperture Synthesis Techniques for Earth Observations at high resolutions from Geostationary orbit.

Key applications identified for this mission are mainly related to disaster and crisis management, to surveillance of dedicated areas and to security purposes. Natural disasters and Maritime security being the most urgently claimed by end users.
Several promising applications that can benefit from OAS image products, are also identified in the fields of environment and resource management thus consolidating the mission plan.

The study was completed by the proposition of an adapted instrument conceptual design and identification of technological development needs.

Pending the identified complementary studies and technological developments, the feasibility of the proposed concept seems to be compatible with a 2020 horizon