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## *Design of the high resolution optical instrument for the Pleiades HR Earth observation satellites*

*Jean-Luc Lamard, Catherine Gaudin-Delrieu, David Valentini, Christophe Renard, et al.*



## DESIGN OF THE HIGH RESOLUTION OPTICAL INSTRUMENT FOR THE PLEIADES HR EARTH OBSERVATION SATELLITES

Jean-Luc LAMARD<sup>(1)</sup>, Catherine GAUDIN-DELRIEU<sup>(1)</sup>, David VALENTINI<sup>(1)</sup>, Christophe RENARD<sup>(1)</sup>,  
Thierry TOURNIER<sup>(2)</sup>, Jean-Marc LAHERRERE<sup>(2)</sup>

<sup>(1)</sup>ALCATEL SPACE, 100 Bd. Du Midi, 06156 Cannes la Bocca – France, E-mail: [jean-luc.lamard@space.alcatel.fr](mailto:jean-luc.lamard@space.alcatel.fr),  
[catherine.gaudin-delrieu@space.alcatel.fr](mailto:catherine.gaudin-delrieu@space.alcatel.fr), [david.valentini@space.alcatel.fr](mailto:david.valentini@space.alcatel.fr), [christophe.renard@space.alcatel.fr](mailto:christophe.renard@space.alcatel.fr)

<sup>(2)</sup>CNES, Centre de Toulouse, 18 Avenue E. Belin, 31401 Toulouse Cedex 4 – France, E-mail:  
[thierry.tournier@cnes.fr](mailto:thierry.tournier@cnes.fr), [jean-marc.laherrere@cnes.fr](mailto:jean-marc.laherrere@cnes.fr)

### ABSTRACT

As part of its contribution to Earth observation from space, ALCATEL SPACE designed, built and tested the High Resolution cameras for the European intelligence satellites HELIOS I and II. Through these programmes, ALCATEL SPACE enjoys an international reputation. Its capability and experience in High Resolution instrumentation is recognised by the most customers.

Coming after the SPOT program, it was decided to go ahead with the PLEIADES HR program. PLEIADES HR is the optical high resolution component of a larger optical and radar multi-sensors system : ORFEO, which is developed in cooperation between France and Italy for dual Civilian and Defense use. ALCATEL SPACE has been entrusted by CNES with the development of the high resolution camera of the Earth observation satellites PLEIADES HR.

The first optical satellite of the PLEIADES HR constellation will be launched in mid-2008, the second will follow in 2009. To minimize the development costs, a mini satellite approach has been selected, leading to a compact concept for the camera design.

The paper describes the design and performance budgets of this novel high resolution and large field of view optical instrument with emphasis on the technological features.

This new generation of camera represents a breakthrough in comparison with the previous SPOT cameras owing to a significant step in on-ground resolution, which approaches the capabilities of aerial photography.

Recent advances in detector technology, optical fabrication and electronics make it possible for the PLEIADES HR camera to achieve their image quality performance goals while staying within weight and size

restrictions normally considered suitable only for much lower performance systems.

This camera design delivers superior performance using an innovative low power, low mass, scalable architecture, which provides a versatile approach for a variety of imaging requirements and allows for a wide number of possibilities of accommodation with a mini-satellite class platform.

### 1. INTRODUCTION

Today Earth observation from space is oriented towards security, whether civilian or military. It provides armies with the strategic data necessary for setting up modern defense to guarantee reliability, regularity and discretion of the information supplied. It is also used for the prevention of civilian risks (pollution, natural catastrophes, climatic change) and the management of terrestrial resources.

Coming after the SPOT program, it was decided to go ahead with the PLEIADES HR program. PLEIADES HR is the optical high resolution component of a larger optical and radar multi-sensors system : ORFEO, which is developed in cooperation between France and Italy for dual Civilian and Defense use. ALCATEL SPACE has been entrusted by CNES with the development of the high resolution camera of the Earth observation satellites PLEIADES HR.

The PLEIADES HR camera concept has emerged from a design-to-cost approach. An appropriate and rigorous trade-off was made between performance and associated technology, so as to guarantee low cost. The selected technologies allow high performance associated with development risk control.

This paper introduces the main constraints of conception taken into account, then presents the design and highlights the key features and performances of the camera.

## 2. CONSTRAINTS FOR CONCEPTION

The constraints for the camera conception are from different kinds:

- constraints link to the electro-optical Earth observation mission and associated performances;
- interfaces constraints with the launcher and the other satellite units;
- development constraints.

### 2.1 Mission and performance requirements

The camera is in charge of Earth imagery covering simultaneously the visible and infrared part of the spectrum in a 30° half-angle cone around nadir performance domain. The telescope field of view (FOV) has to cope with a 20 km nadir swath need. The demanding Panchromatic resolution has to be better than 1.00 m in the performance domain (0.70 m at nadir), and the 4 spectral bands with a 4 time Pan resolution are adding up green, red and near infra-red plus blue bands in order to reach natural color. All these major requirements for a small imaging satellite sensor imply significant improvement of every subsystems of the instrument.

A very high maneuver capability of the satellite is also required to offer an optimal Earth mapping coverage, that leads to severe mass and inertia requirement. Consequently, the camera is integrated vertically inside the bus.

The very compact configuration and the camera stability are optimized for image quality. The entrance aperture diameter and the stability between optical components determine modulation transfer function (MTF) performance. The optical heads of star trackers and FOG inertial unit are mounted on the camera for maximum geometrical quality accuracy.

The choice for image device has been restricted to charge couple device (CCD) image sensors for maturity reasons of that technology and its Earth observation missions well adapted performances.

Thanks to the needs in terms of ground sampling distance, swath width and number of spectral bands, the radiometric performance optimization at lowest costs is achieved with complete video processing entirely integrated on the focal plane.

The camera architecture complies at least with the concept of progressive degradation of the mission

performances that ensures reliability of « essential » mission.

### 2.2 Interfaces constraints

A generic and compact camera architecture has been selected to allow for a wide number of possibilities of accommodation with a mini-satellite class platform interface requirements.

Low mass and high compactness favour small launchers compatibility. Mechanical design has been driven by the launchers : Rockot and Soyuz, as the choice between them hasn't been done at that time for PLEIADES HR.

Thermal design has been driven by the orbit choice (SSO 694.9 Km and 10h15 LHDN) and the satellite configuration.

The instrument electrical architecture minimizes power consumption and interfaces the bus trough 1553 standard except power distributed by the DRU (unregulated 28±7 VDC).

### 2.3 Development constraints

Small imaging satellite mission offers many advantages. Among these is its lower cost, a result primarily of its smaller size and economies due to multiple-unit production for many missions. Short lifetime (5 years) also improve turnaround time of new technology.

These objectives lead to significant development constraints. Tight schedule and many new developments impose:

- risk management with anticipated actions to reduce the risks associated to the development;
- very high reactivity and flexibility in order that the convergence can be achieved efficiently in concurrent engineering.

Indeed the camera design benefits from recent advances of new lighter and more efficient technologies. The major technological breakthroughs are described in the table 1 below.

Furthermore, the PLEIADES HR camera program benefits from ALCATEL SPACE long and successful heritage in Earth observation from space. The corresponding design and production teams are experienced and well trained.

The proposed solution benefits from an extensive use of existing products for the High Resolution cameras for the European intelligence satellites HELIOS I and II (camera alignment procedures, telescope thermal control and mechanical assembly principles, video processing techniques, ...).

Equipment	Technology	Major Interest
Panchromatic Detector	TDI CCD detector with anti-blooming structure	High resolution imaging without satellite slowing. No light spreading due to blooming.
Very long multi-spectral stripe-filters	Assembly of a single substrate with 4 stripe-filters over the detector window	Separate the different spectral bands in the FOV. Minimize chromatic aberrations.
Highly Integrated Detection Unit	Integrated Focal Plane and Video Electronics. High integrated ASIC technology.	Compact detection function integrated in the camera
Telescope	Carbon / carbon structure	Low mass / high thermal stability

Table 1. Major technological breakthroughs

All the production facilities (equipment production, camera integration) are also readily available. ALCATEL SPACE owns a space optics centre unique in Europe :

- 1000 m<sup>2</sup> of clean rooms in a single space, including 500 m<sup>2</sup> in class 100;
- 2 vacuum chambers each equipped with an optical bench, including the largest optical bench in Europe;
- optical, electrical laboratories;
- measuring instruments (interferometers, theodolites, integrating sphere, etc.);
- specific techniques (collimators, flat mirrors, etc.).

The willingness to develop an ITAR free camera is noticeable : the proposed design only relies upon in-house products for the critical components and subsystems as well as for a large part of the non-critical items and upon multi-source classical procurement sources for the rest of the non-critical items.

Instrument design has reached a good maturity. Pre-development activities started in 2002 for critical and/or technological items. PLEIADES HR instrument delivery is planned in January 2007 for QFM, 2<sup>nd</sup> half of 2007 for FM2, and the satellite launch is planned mid-2008 for FM1, 2<sup>nd</sup> half of 2009 for FM2.

The PLEIADES HR camera program is now entering into its detailed definition phase.

### 3. CAMERA DESIGN OVERVIEW

#### 3.1 Detection technique

The camera concept is a push broom imager. The telescope images simultaneously all the points of a line on the ground on detector arrays located in the focal plane and optically butted together to form a single row for each spectral bands, providing spatial resolution in one direction (cross-track). Forward motion of the satellite causes this line to scan in the direction perpendicular to it (along-track), thereby producing two-dimensional images in multiple wavelength bands.

The use of CCD TDI mode of operation for the panchromatic band increases photosensitivity allowing very high spatial resolution at low radiance levels. The MTF and signal noise ratio (SNR) of Pan images are improved.

#### 3.2 Camera overall configuration

An overview of the camera is presented below (Fig. 1). Starting from the light beam entrance, it is constituted of:

- The optical telescope based on the KORSCH combination. The imager design is an all-reflective 4 mirrors telescope with light-weighted Zerodur optics and a carbon structure.
- The shutter mechanism located behind the M1 mirror. It protects the detection unit from direct solar entrance.
- A thermal refocusing device included in the mirror M2 assembly. It allows in orbit focusing of the telescope.
- The detection unit mounted on the telescope and composed of two main assemblies : the focal plane assembly (FPA) ensuring the spectral separation in the field of view and transforming the incoming optical signal in electrons, and the video electronics interfacing with the FPA and the satellite on board image chain.
- The service electronics located in the bus and composed of two unit : a dedicated unit for video power supply and the instrument in/out unit which interfaces with the satellite and ensures the instrument command and control.

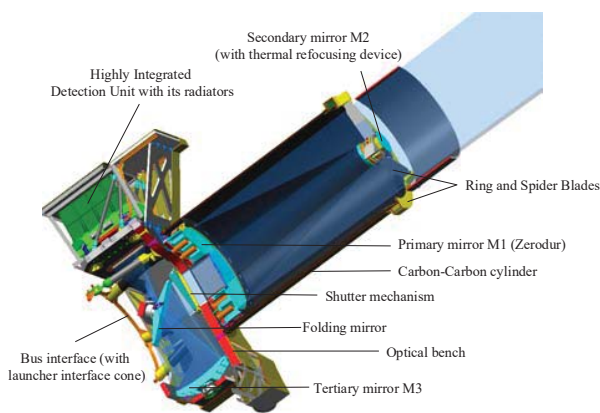


Fig. 1. Camera exploded view

4. CAMERA OPTICS

The optical design of PLEIADES HR (Fig. 2) is based on a compact KORSCH combination, assembling an on axis part (M1 + M2 collector mirrors) and an off axis part (M3 + MR mirrors) feeding the different focal planes. The design features a 650 mm aperture and a 12.9 m focal length.

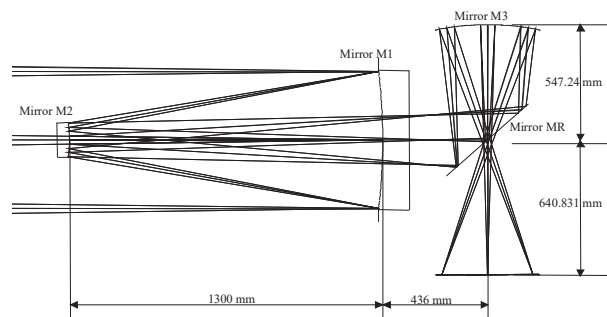


Fig. 2. Optical configuration

This optical lay-out provides great interest in term of accommodation. Its low speed (~F/20) allows an easy folding beam behind the M1 mirror. The volume is then restricted to less than 1.9 m length and 1.2 m in maximum diameter. More over, the low speed leads to a positioning sensitivity in the class of 10 μm focus (the more constrained axis).

The four light-weighted Zerodur (class 0) mirrors equipped with monolithic Invar mirror fixation devices (MFD) provide high performance optics (Table 2).

In order to not distort the optical surfaces, the MFD are designed to provide decoupling between the mirror and the interface plane against flatness errors, thermal expansion differences and also limit to a reasonable extent, the risks of dynamic coupling between the mirror and the support structure.

The production of the MFD makes use of wire electro-erosion, proven to give good results for such types of application.

A key technology for manufacturing of high performance optics is the polishing technique, which is used to do at least the final correctives steps of surface generation. Ultrafine mechanical computer controlled polishing machine (CCPM) has been selected because it is well operational for large optics with low F number, it allows to have low roughness surface (<3Å) and surface flatness compatible with Marechal’s condition (RMS<λ/28), it is demonstrated for off-axis aspherical polishing. Furthermore the selected CCPM for the production of the M2 mirror is based on a magnetorheological principle leading drastic improvements of the final quality, compared to conventional CCPM’s. But it is limited to typically 300 mm in diameter.

The radiometric requirement is met with protected silver coating on the mirrors surface.

	M1	M2	M3	MR
Useful zone	Ø 660 mm	Ø 168 mm	415 mm x 99 mm	434 mm x 65 mm
Mirror shape	concave quasi-parabolic	convex aspherical	concave aspherical	plane
Curvature (mm)	3185.45	-724.90	927.86	
Offset	-	-	69.8 mm	-
Weight (including MFD)	< 22.7 Kg	< 1.6 Kg	< 3.6 kg	< 1.9 Kg
RMS WFE (except tilt and focus)	28 nm	18 nm	22 nm for each Ø 61 mm sub pupil	15 nm for each Ø 47 mm sub pupil
Deviation between 2 sub pupil	-	-	< 10 μm (piston) < 5 μrad (tilts) < 6 nm PTV (focus)	

Table 2 : Mirrors design and performance

Within the PLEIADES HR study special effort was devoted to the camera alignment procedure. This starts at design. The secondary and the tertiary mirrors are left respectively with five and two degrees of freedom which are carefully designed for precise alignment. Alignment of the elements requires computer aid and highly computer aided interferometric measuring technology. The telescope is then aligned to the required root mean square wave front error (accuracy ≤ 12 nm RMS) and output pupil accuracy positioning (≤ 1.7mm) in relation with output pupil diaphragm position.



On one hand the two diaphragms located in the intermediate focal plane and at the output pupil, and on the other hand the mask in the shade of the M2 mirror on the M1 mirror prevent from stray light on the detector.

### 5. OPTO-MECHANICAL DESIGN AND MATERIAL

Under a stringent thermal environment, the sensitivity of the compact optical lay-out combined to a relatively high-resolution / pupil diameter-ratio, lead to a very high stability requirement on the structure to fulfill the performances; especially for the M1-M2 link, as the defocus (along optical axis) is a major contributor to telescope WFE degradation.

Therefore carbon / carbon (C/C) composite has been selected by ALCATEL SPACE as a key material for camera structure for the following reasons (Table 3) :

- Very high thermoelastic stability : coefficient of thermal expansion (CTE) close to zero in a quasi isotropic lay-out configuration.
- Low density with good mechanical properties allowing simple and reliable analyses.
- Moisture insensitivity.
- Various architectural possibilities adapted to efficient structural concepts.
- Industrial maturity.

Density	1.6 gcm <sup>-3</sup>
CTE	-0.1 x 10 <sup>-6</sup> K <sup>-1</sup>
Tensile strength	> 160 Mpa
Interlaminar shear strength	> 12 Mpa
Tensile modulus	> 60 Gpa

Table 3. C/C properties

However the choice of materials has been done also to reach the stability needs within the lowest cost.

Thus, different structural architectures and materials have been investigated to finally select, as the best appropriate candidate (Fig. 3) :

- A primary structure for M1-M2 structure built around a C/C cylinder combined with carbon-cyanate M2 spider blades and reinforcement ring.
- A aluminum nida / carbon-cyanate optical bench supporting the telescope elements : M1, M3, MR, Detection Unit, Star Trackers and FOG Inertial Measurement Unit (optical core), Shutter.
- Three bipods with RTM tubes to support the camera and to interface the bus structure.

The primary structure equipped with thermal control design provides an interesting mass (<125 Kg) for such a telescope which has to withstand high loads and presents a very high stability performance. This architecture allows a versatile design which can be easily adapted for different telescope geometries and offers a large compatibility with the existing launchers.

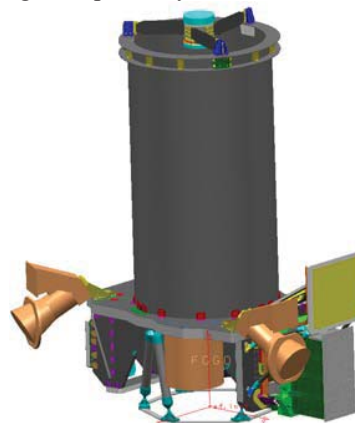


Fig. 3. External camera view

A robust thermal control is implemented and consists of multi-layer insulation (MLI) for efficient thermal protection of the overall camera and passive cooling plus heaters monitored by high precision platinum probes (PI regulation). A radiated thermal control in the M1 mirror light-weighting cells drives the camera WFE stability, whereas the detection unit is isolated and makes use of heat pipes and dedicated radiator to drain the power dissipation.

A thermal refocalisation device included in the M2 structure offers possibility of re-align optics during flight mission. This solution is lighter (mass) and cheaper than a mechanical one, in preserving performances. The requirement is an ability of 33,5µm PTV displacement for the M2 mirror with stability (focus : ± 0.8µm - tilts : ± 5µrad) and no mirror distortion induced. The design is based on the temperature controlling of an aluminum ring located between mirror and structure (Fig. 4). The functioning temperature range [17°C ; 34.5°C] is compatible with a 23°C thermal controlled camera.

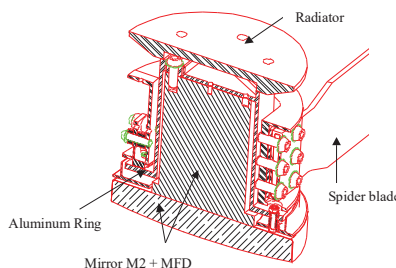


Fig. 4. Thermal refocalisation device

The main purpose of the shutter mechanism is to protect the detection unit from direct solar entrance. It shall be closed in less than 2 second in case of satellite loss of attitude and is located in a limited volume behind the M1 mirror. An hybrid stepper motor with redundant windings moves a flap from the one to the other steady state position : open and close.

## 6. FOCAL PLANE DESIGN

The focal plane (Fig. 5) is the heart of the highly integration detection subassembly (Fig. 7). The size of the observed image is close to 400 mm and is analyzed in 30,000 samples in Pan and 7,500 in Xs.

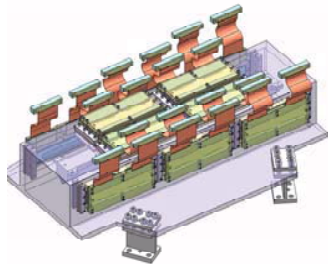


Fig. 5. Focal plane assembly

The Pan band is constituted of 5 TDI mode CCD arrays, which the pixels are of PhotoMOS type with lateral anti-blooming structure. The image section has 6000 columns of active pixels each  $13 \mu\text{m}$  square and is clocked continuously to give a time-delay-and-integrate (TDI) function. The transfer of charge along the CCD is made synchronous with the velocity of the scan image. The integration time is  $m$  times longer than a single-detector integration time, where  $m$  is the number of stages in a row. Since the noise is proportional to  $m^{1/2}$ , the SNR improvement over a single detector is also  $m^{1/2}$ . Within the image section are 4 separately connected electrode groups to enable the TDI length to be varied. The electrodes of the image section are of the four-phase type. The full-well capacity ( $> 130 \text{ K}$  electrons) is largely set by the channel doping and the anti-blooming "barrier height", i.e. the well depth at which charge spills to drain. Below the image section is a register that is split into 10 sections, each with a separate output circuit.

The colored bands (XS) are constituted of 5 CCD four linear arrays. The spacing between the centers of each line and the next is  $936 \mu\text{m}$  allowing the necessary area for the readout registers and associated bus structures for each line. The photo-sensing element of the pixel is a photodiode. Each line of pixels has 1,500 photo-elements on a  $52 \mu\text{m}$  pitch and the size of each photo-element is  $52 \mu\text{m}$  square. Signal charge generated in the photodiode is initially collected under an adjacent

CCD electrode. Transfer of charge from the storage gate to the read-out register is under control of a transfer gate. Within the storage gate area is an anti-blooming structure. The full-well capacity meets the  $130 \text{ K}$  electrons minimum saturation requirement. The structure of the readout registers is composed with 2 register elements for each of the photo-detection pixel sites, using two phase technology. Thus the readout register is operated at twice the required pixel frequency and the output signal is making up after summing in the output circuit.

The standard detector package consists of a co-fired Aluminum Nitride (AlN) ceramic body with dual in line pins on the underside. The window is in BaK50 with an antireflection coating on both sides.

The spectral selection is made by optical filters placed very close in front of the detectors. Pan filters and XS strip lines filters (Fig. 6) are space-qualified multi-layer coating deposited on glass substrates. Each filter is composed of high-pass filter and low-pass filter. An absorbing material deposited between the XS filters isolates each band from the others to avoid inter-band stray-light.

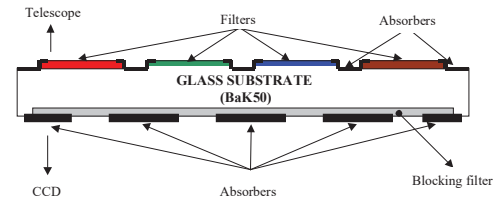


Fig. 6. XS filter design

One of the key features of the FPA is the extensive use of mechanical parts made of SiC. This material offers a very good thermal conductance leading to a simplified thermal concept, a low CTE for acceptable dimensional stability thanks to this class of camera featuring a low optics speed, and a very high mechanical rigidity for a low mass.

A Sic main structure ensures accurate positioning and thermal dissipation.

For an easy high level image products ground processing, optical butting with splitting Zerodur mirrors provides the continuity of the detection lines (Pan/Pan and XS/XS in the field registration) and folding with long roof Sic mirror separates Pan and XS image (Pan/XS  $1.58 \text{ mrad}$  maximum in the field separation).

For its integration in the focal plane, each detector is equipped with a mechanical frame of SiC glued on the

detector package in AIN. This frame fixes the detector on the focal plane structure and supports the front-end electronics with its shielding. This innovative architecture provides a versatile building block for a variety of imaging requirements.

The high integration level requires to use specific connecting parts : the link is made with flexible circuits optimized to operate at frequency close to 7 MHz and with the constraint of distance of typically 10 cm between the focal plane and the video electronics.

## 7. CAMERA ELECTRONICS

The video electronics are mounted on the telescope (behind the focal plane), all video functions associated to one or two CCD are integrated on a single board, and the 70 video chains interface the compression and mass memory unit with 15 redundant very high speed digital links (Agilent HDMP-1032).

The design of the video electronics is driven by the high data rate required by the high resolution, the video signal profile and the stringent specified radiometric accuracy. The pixel frequency required is 6.5 MHz for Pan band and 3.7 MHz for XS bands. For video processing, CCD phase driving and digitally programmable delay no satisfactory standard component has been found. For this reason, CNES and ALCATEL SPACE have developed 3 analog/mixed ASICs corresponding to these 3 functions. They have been designed for 1 to 10 megapixel/s high accuracy readout of CCD detectors and have been developed in RHIC3 BiCMOS 1.2  $\mu\text{m}$  Rad Tolerant technology.

The CLBNG ASIC is a versatile wide-band analog CCD front-end circuit for video acquisition and processing. Its architecture is fully differential and allows 2 multiplexed inputs. It includes correlated double sampling, 12 bit DAC for offset correction and a digitally programmable internal voltage reference. It provides simple and efficient interfaces with most A/D converters.

The FAST ASIC is a versatile phase generator circuit for driving CCD. It includes 2 independent channels programmed by a common serial interface (setup of rise/fall time); high and low levels are externally tuned. It provides compatibility with most CCD available from the market.

The TRIM ASIC is a versatile digitally programmable delay circuit. It provides delay on rising edge and falling edge independent and includes 4 channels with delay range from 0 to 100 ns with 1 ns step.

On the basis of these ASICs, two types of hybrid have been developed :

- Video processing hybrid, which includes 2 complete video processing chains. Each processing chain is based on a CLBNG ASIC, an TRIM ASIC, a 12 bits ADC (LTC1420), a digital ASIC (AOF2) for offset correction processing and few passive components. Compared to the previous video processing chain (Spot V), these chains exhibit a gain of two for the maximum pixel frequency and a gain of five for power and size.
- CCD phase driver hybrid (ICARE), which is able to drive 4 CCD phases, and based on 2 FAST ASICs, a TRIM ASIC and few passive components.

Due to their low power and size budgets, these basic functions provide a low mass, low volume and low power consumption for the highly integrated detection unit.



Fig. 7. Detection unit

The dedicated unit for video power supply is located in the bus and consists in 4 independent board set (3 boards combining with 1 or 2 Pan CCD and 1 board combining with all XS CCDs). Its design is based on ALCATEL standard converter modules (CVST40) which use high output flyback converter with very high accuracy in a wide output power range.

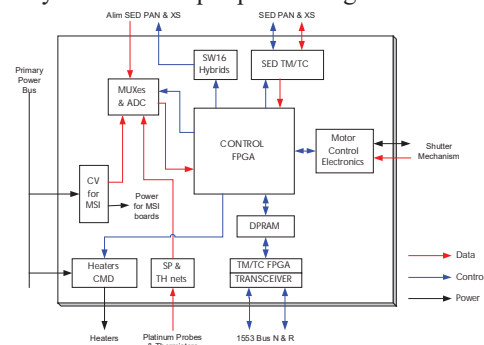


Fig. 8. Instrument in/out functional diagram

The instrument in/out unit consists in two redundant board sets located in the bus. It serves as interface between the bus and the instrument by means of a 1553 bus. Its main tasks are the control and management of the different components of the instrument, which are, in addition to itself :



- thermal control module, based in a series of heaters and temperature sensors,
- detection unit, which contains Pan and XS channels,
- shutter mechanism.

The core of the unit is implemented into two FPGAs : ACTEL 54SX72 (which are the biggest ITAR free device available); the capacity provided by these devices is enough for the PLEIADES HR instrument requirement.

## 8. PERFORMANCE ESTIMATES

The PLEIADES HR instrument performances are listed in Table 4.

Parameter	Performance	Comments
Ground sample distance	0.7 m (Pan) 2.8 m (XS)	At nadir, from 694.9 Km altitude
Telescope Aperture	650 mm F/20	For resolution and SNR
Swath width	20 Km	At nadir
Spectral range	480 - 820 nm 450 - 530 nm 510 - 590 nm 620 - 700 nm 775 - 915 nm	Panchromatic Blue Green Red Near infra-red
MTF ( $f_0$ ) minimum statistical value (99.7% value)	Pan > 0.083 (raw) [Pan > 0.2 after MTF restoration] XS > 0.2	$f_0=1/(2p_0)$ $p_0$ is the spatial length of interest
SNR minimum statistical value (99.7% value)	>114 (Pan) > 90 (XS)	Worst case at L2 radiance
High frequency inter-column noise	<2 x column noise	Non linear radiometric model
Pointing stability (for localization)	< 4.8 $\mu$ rad	Between line of sight and star trackers or fiber optic gyros
Distortion	< 2.3 %	Pan band
Registration (maximum angular distance)	< 1.58 mrad < 0.5 mrad	Pan / XS Inter / XS
Useful output data rate	3.90 Gbits/s 0.888 Gbits/s	Pan XS
Power consumption	26 / 375 W < 115 W	Electronics Thermal control
Mass	< 227.5 Kg	Video power supply and instrument in/out units included
Reliability	> 0.818	5 years in orbit (normal mission)

Table 4. Instrument performances summary

## 9. CONCLUSION

ALCATEL SPACE offers a family of small-satellite space borne imaging cameras enable to satisfy the space remote sensing market (defense and security customers, scientists and civilian institutional customers, commercial customers), based on its experience gained over the previous decades and now with the PLEIADES HR camera program.

The cameras fully meet panchromatic and multispectral systems sensing requirements. These camera designs deliver superior performance using a low power, low mass and scalable architecture. The overall design philosophy is to use proven technology and in-house products for a low-risk and low cost-system.

This complete range of innovative architecture provides a versatile approach for a variety of imaging requirements and covers a wide variety of areas for possible missions, such as wide-area surveillance and multi-spectral remote sensing : military information, range finding, mapping, ground, ocean and resources supervision.

## 10. ACKNOWLEDGMENTS

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## 11. REFERENCES

1. Fayret J.P., Gaudin-Delrieu C., Lamard J.L., Devilliers C., Costes V., *Instrument concept for a high resolution and large field of view Earth observation mission*, ICSO 2000.
2. Devilliers C., Nivet M., Coperet H., *Advanced Carbon / Carbon Material for Space Telescopes Structures*, IAF-01-I.3.08.
3. Dantes D., Neveu C., Biffi J.M., Devilliers C., Andre S., *A new generation of detection electronics for Earth observation satellites*, ICSO 2000.
4. Plaisant G., Le Goff R, Deswarte D., Corlay G., *Design of the FOCAL PLANE for the PLEIADES instrument*, IAC-02-B.3.05.
5. Laubier D., Mercier-Ythier R., *Very long stripe-filters for a multispectral detector*, ICSO 2000.