International Conference on Space Optics—ICSO 2004

Toulouse, France

30 March–2 April 2004

Edited by Josiane Costeraste and Errico Armandillo

Design and development of the 2m resolution camera for ROCSAT-2

Gilbert Uguen, Philippe Luquet, François Chassat

International Conference on Space Optics — ICSO 2004, edited by Errico Armandillo, Josiane Costeraste, Proc. of SPIE Vol. 10568, 105680M · © 2004 ESA and CNES
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2307961

DESIGN AND DEVELOPMENT OF THE 2m RESOLUTION CAMERA FOR ROCSAT-2

Main author: Gilbert Uguen
EADS Astrium 31 Avenue des Cosmonautes 31402 TOULOUSE Cedex 4 France
gilbert.uguen@astrium.eads.net
Co-authors: Philippe Luquet
Philippe.luquet@astrium.eads.net
François Chassat, and the RSI team
Francois.chassat@astrium.eads.net
EADS Astrium 31 Avenue des Cosmonautes 31402 TOULOUSE Cedex 4 France

1 INTRODUCTION

EADS-Astrium has recently completed the development of a 2m-resolution camera, so-called RSI (Remote Sensing Instrument), for the small-satellite ROCSAT-2, which is the second component of the long-term space program of the Republic of China. The National Space Program Office of Taïwan selected EADS-Astrium as the Prime Contractor for the development of the spacecraft, including the bus and the main instrument RSI.

The main challenges for the RSI development were:

- to introduce innovative technologies in order to meet the high performance requirements while achieving the design simplicity necessary for the mission (low mass, low power),
- to have a development approach and verification compatible with the very tight development schedule

This paper describes the instrument design together with the development and verification logic that were implemented to successfully meet these objectives.

2 ROCSAT-2 MISSION AND SATELLITE

The ROCSAT-2 mission mainly aims at monitoring the terrestrial and marine environment and resources throughout Taïwan with:

- a high re-visit frequency (1 day re-visit),
- a large coverage of Taïwan,
- high panchromatic and multi-spectral imaging performances.

The solution proposed by EADS-Astrium was based on the LEOSTAR generic platform pre-developed by EADS-Astrium and addressing a wide range of missions, from earth observation to scientific missions (Mars Express, Rosetta).

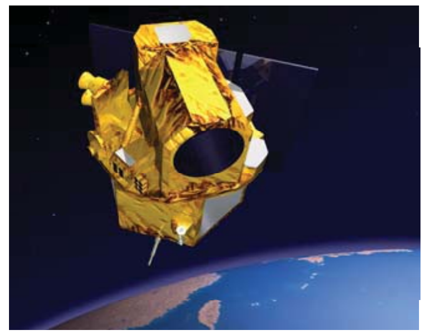

Figure 1: Overview of ROCSAT satellite

For the purpose of the mission, a helio-synchronous orbit of 891km was selected to satisfy the 24-hours revisit time.

Thanks to the platform pitch/roll performance capability (+/-45°), a multi-strip approach was offered in response to the large coverage requirements

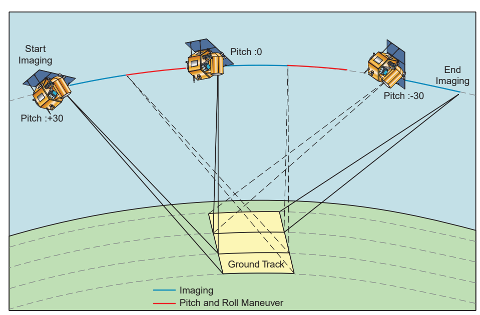

Figure 2: Multi-strip approach

The Remote Sensing Instrument (RSI) of ROCSAT-2 satellite provides a 2m Ground Sampling Distance (GSD) in Panchromatic (PAN) band, and a 8m GSD in multi-spectral (MS) bands, over 24 km swath width, in the Nadir direction.

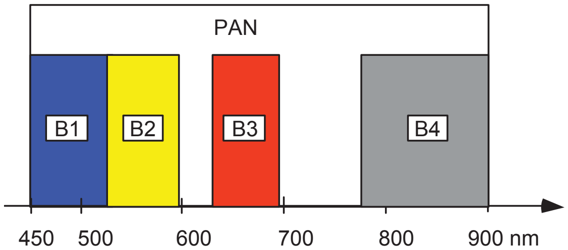

Figure 3: RSI spectral bands

3 RSI DESIGN

3.1 RSI overall configuration

The Instrument features two main parts:

- The push-broom camera which includes the telescope and the Focal Plane Assembly (FPA) attached to the rear side of the telescope:

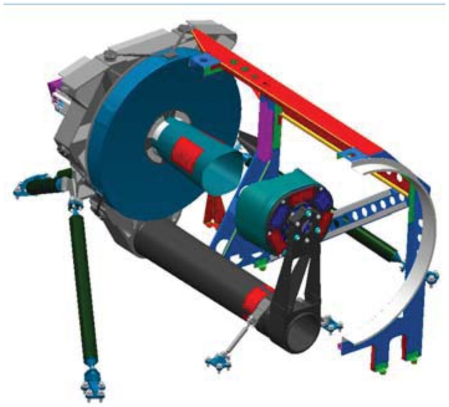

Figure 4: Camera configuration

- Two Instrument Processing Units (IPU) mounted in cold redundancy inside the Bus and whose functions are to ensure the video data processing, the data compression and the telemetry/telecommand data processing (including thermal acquisition and control).

3.2 RSI Camera

◆ Telescope optical concept

The camera is based on a compact Cassegrain-type telescope and a four-lenses field corrector

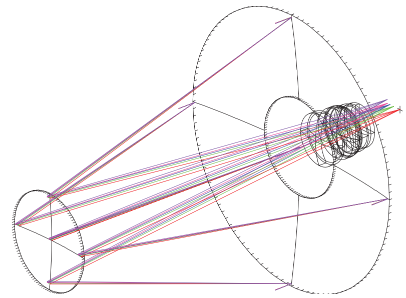

Figure 5: Telescope optical concept

Focal Length	2896 mm	
Pupil Diameter	600 mm	F/N = 4.83
Field of View	+/- 0.8°	
Optical Quality	WFE < 40 nm rms	

Figure 6: Optical Sub-assembly characteristics

◆ Silicon carbide for mirrors and structure

The RSI design is based on an all-SiC opto-mechanical architecture (telescope structure, mirrors, and focal plane structural elements).
This monolithic design approach, combined with the intrinsic SiC100 properties (high stiffness, low density, low thermal expansion, high thermal conductivity) allows to combine a high level of stability together with a low mass.

- Low mass: telescope mass ~ 60 kg,
- High Rigidity: first Eigen frequency >100Hz,
- High mechanical stability: inter mirror stability lower than 5µm,
- High thermo-elastic stability: quasi a-thermal configuration.

◆ Telescope structure

The telescope structure is only featuring three main parts: the main plate (supporting the primary mirror), the secondary mirror support, and the rod connecting those two parts.

Figure 7: Telescope structure

Telescope mirrors

SiC mirrors can be light-weighted and polished with a high accuracy. Both mirrors were SiC CVD[1] coated before polishing in order to minimize the roughness The Wave-front Error (WFE) was measured below 20 nm rms for each mirror, with a roughness lower than 1.0 nm rms.

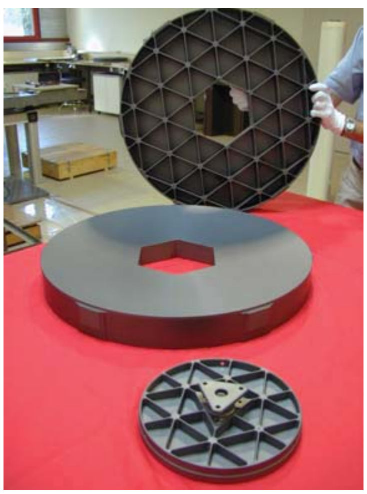

Figure 8: Primary & Secondary blank mirror

	Primary Mirror	Secondary Mirror
Dimensions	D 600mm H 70 mm	D 240mm H 50 mm
Mass	11.6 kg	1.2 kg
Optical Quality	< 25 nm rms	< 22 nm rms

Figure 9: Mirrors main features

[1] CVD: Chemical Vapor Deposition

Refocusing capability

The secondary mirror is fixed on the structure by its interface flange. The primary mirror is fixed on to the structure through three iso-static invar mounts and thus thermally decoupled from the structure. Its temperature is controlled by a heater plate located between the mirror and the mounting plate. Setting different thermal control set points between the telescope structure and the primary mirror leads to a variation of the focal plane position, thanks to the low - but non-null – thermal expansion coefficient of silicon carbide. The refocusing capability is +/- 200µm for a +/- 5°C thermal set point variation.

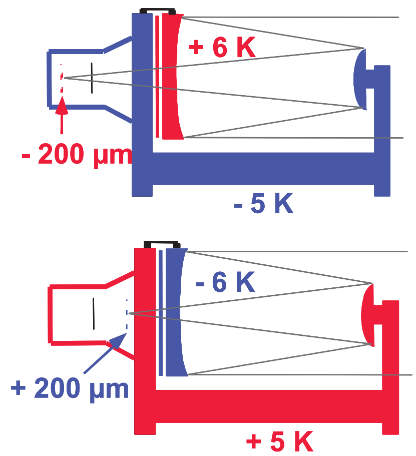

Figure 10: Re-focus principle

Focal Plane Assembly (FPA)

The focal plane assembly features only two CCD for the 5 required spectral bands.
One CCD is dealing with the Panchromatic band and the other one is dealing with the multi-spectral bands. The separation of the entrance optical bean is ensured by an optical field separator.

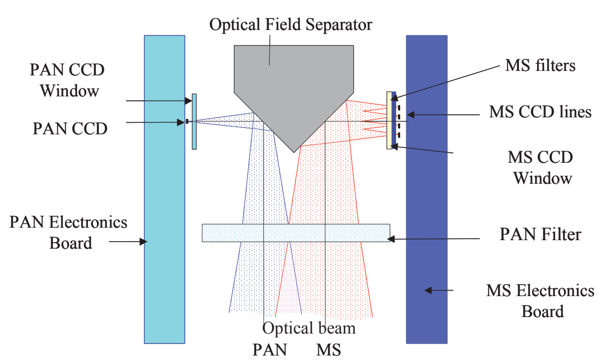

Figure 11: FPA optical design

A 4-line CCD for Multi-spectral bands

ROCSAT2 took benefit of the pre-development performed by Atmel, under a CNES R&D contract. The TH31547 multi-spectral CCD consists of 4 photo-detector lines, each line being made of 6000 photodiodes with 13µm step. The detector is operated at 5 Mpixel/s per video output.

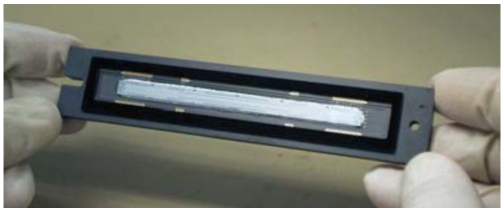

Figure 12 : The quad-linear CCD

Each CCD line is coupled with a spectral band filter. The four slit filters are coated on the same glass substrate glued on the CCD.

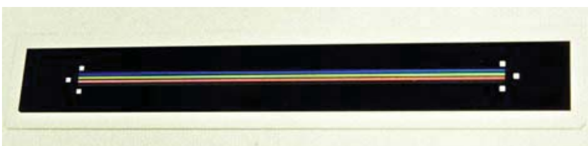

Figure 13 : MS filter

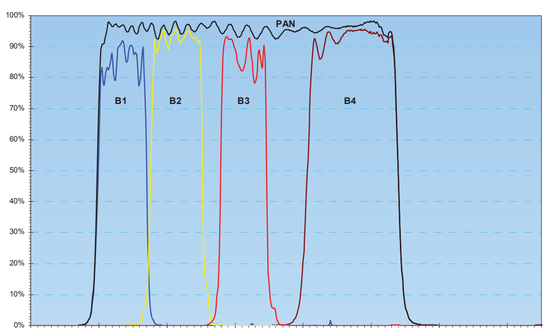

Figure 14 : PAN and MS transmission

High speed video processing for the panchro- matic channel

The panchromatic detection chain is based on the well-known TH7834B detector (12000 useful 6.5 x 6.5 µm²) pixels). The challenge was to operate the four serial read-out registers at a 10 MHz pixel rate for satisfying the 308µs integration time required to achieve the 2-meter resolution.

Figure 15: The 12000 pixels Panchromatic CCD

Front end electronics

Each CCD is connected to a dedicated front-end-electronic board which ensures the clock driver distribution and the video signal pre-amplification.

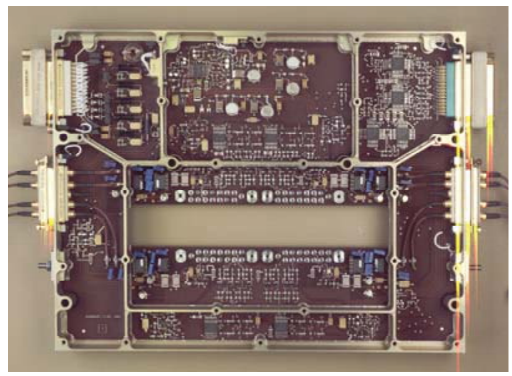

Figure 16 : The PAN Electronics Board

Integrated FPA

Figure 17 : integrated FPA

Dimensions	L 370 x W 200 x H 260 mm^3
Mass	8 Kg
Power	30W

Figure 18 : FPA main feature

3.3 Integrated Video Processing Function

The Instrument Processing Unit (IPU) is gathering the instrument electronics functions in a modular and highly integrated assembly.
The IPU is coupled with the Focal Plane Assembly front-end electronics - Panchromatic Electronics Board (PEB) & Multi-spectral Electronics Boards (MEB) – and also with three Spacecraft main units: the On Board Management Unit (OBMU), the Solid State Recorder (SSR), and the Distribution & regulation Unit (DRU).

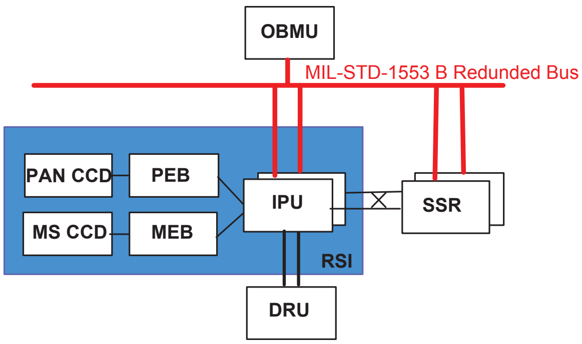

Figure 19 : IPU interfaces

Each IPU includes the necessary functions:

- to operate both CCD detectors - through the front end electronics located in the FPA
- to process the video analogue signal and to condition and to digitise all the pixel values,
- to compress the data flow with an improved adaptative rate regulated JPEG algorithm,
- to ensure the instrument thermal control.

These functions are split on seven electronics boards racked in the same unit.

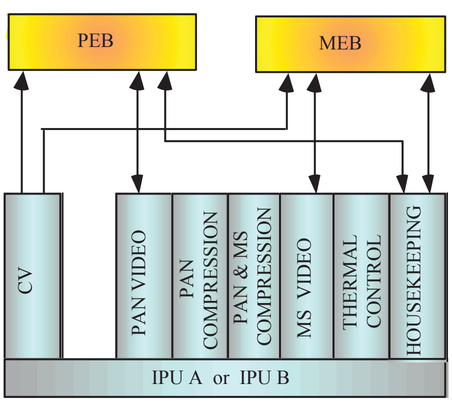

Figure 20 : IPU Architecture

Mass	14.5 kg
Dimensions	L 345 x W 280 x H 250 mm^3
Power	110 W in imaging mode

Figure 21 : IPU Main features

Figure 22 : The Instrument Processing Unit

3.4 RSI Main Characteristics

	PAN	MS
Mean radiance (Rm)	≈ 100 W.m^{-2}.sr^{-1}.µm^{-1}	
S/N @ 1.3 Rm	90	~ 150
CTF (square wave MTF)	0.12	0.25
Focal plane		
Integration Time	0.308 ms	1.232 ms
Processing rate per video output	10 Mpixels/s	5 Mpixels/s
Data Processing		
Pixel encoding	12 bits	12 bits
Data selection	8 bits 10 gains	8 bits 10 gains
Compression ratio	2.8 & 3.75	1.7 & 3.75
Overall Characteristics		
Dimensions	L=1800mm W=780mm H=905mm	
Mass	Camera: 85 Kg 2xIPU: 29 Kg	
Power	Imaging: 110W	

Figure 23: RSI main characteristics

4 DEVELOPMENT AND VERIFICATION APPROACH

To cope with the required tight development schedule (2.5 years), a straightforward approach was necessary. This approach concerned two main areas:
- The industrial organization
- The model and verification philosophy

4.1 Industrial organization

The key issue was to favour the flexibility and reactivity in terms of design, development and verification activities. This led to a two-step approach consisting in:
- Keeping in-house the maximum of responsibility regarding the instrument design (down to component level) and AIT,
- Being supported by "state-of -the art" partners for the key technologies and being part of a core team working in close relationship all along the design and development phase.

The main partners were:

CCD	ATMEL
Multi-spectral filters	BARR Associates(US)
Optics (mirrors and corrector)	SAGEM
SiC structure and mirror blanks	Boostec
Electronics (PEB/MEB/IPU)	Astrium VELIZY

Such an organization and partnership allowed to have an efficient and fruitful concurrent engineering phase at the very beginning of the program in order to consolidate at an early stage (T0 + 3 months) the equipment specifications of the schedule critical items.

4.2 Model and verification philosophy

The selected approach was to develop a single model of the Instrument (Proto-Flight Model), but to mitigate the risks by conducting pre-validation activities where deemed necessary.

- ***Supporting programs***

Two main areas of concern were identified:
Detection:
- Need to confirm the PAN video chain performances with the TH7834 working at 10 MHz pixel output rate (twice the readout frequency of SPOT5)
- Need to have an early validation of the operating conditions of the brand-new multi-spectral TH31547 CCD and of the associated performances (main concern related to potential cross-coupling between bands).

Opto-mechanical aspects:
- Need to have an early validation of the overall instrument stability, and particularly:
  - o the telescope inter-mirror stability in view of the high amplification factor regarding de-focus effects (factor of 20),
  - o the FPA internal stability.

Therefore, two support programs were conducted :

Detection support campaign

This support program consisted in testing and characterizing the detection chains operating conditions and performances (PAN & MS) using a Focal Plane Assembly and Instrument Processing Unit Development Models (DM).

Mechanical support campaign

This support program consisted in verifying the telescope stability by testing a Structural Model (SM) of the Instrument. This SM was built of the telescope structure flight model equipped with mirror blanks and the FPA DM
The stability of the structure was verified using a 3-D machine.

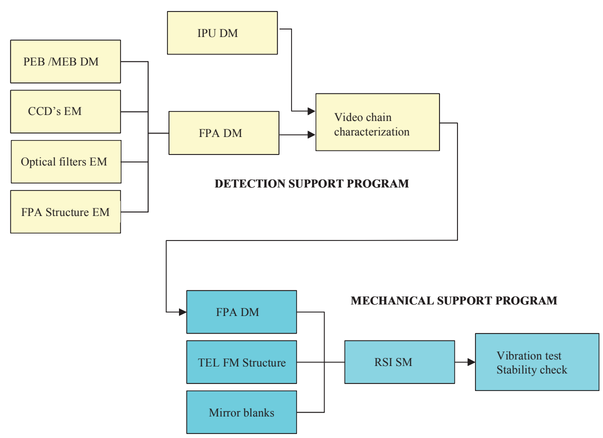

Figure 24: support programs

Figure 25: SM test campaign

4.3 Proto-flight assembly and qualification tests

◆ ***RSI Assembly and integration***

The RSI FM AIT started at the completion of the support programs and delivery of the telescope mirrors.

Figure 26: FM camera integrated

◆ ***Proto-qualification tests***

All the environmental tests were performed at the same place (Centre Spatial de Liège). The qualification sequence was the following:

Vibration tests

The Instrument was submitted to low level sine vibration and quasi-static load tests (15g axial, 9g lateral). The compatibility with the specified acoustic levels was in a first step demonstrated by analysis and tested at spacecraft level.

Figure 27 : Sine vibration tests

EMC tests

The Instrument was submitted to EMC conducted susceptibility and emission tests. The compatibility with the EMC radiated levels was in a first step verified at IPU unit level and then switched to Spacecraft level with a full representative environment.

Figure 28 : EMC test configuration

Thermal vacuum tests

The test sequence consisted in a thermal cycling phase followed by the operational cold case / hot case performance tests.

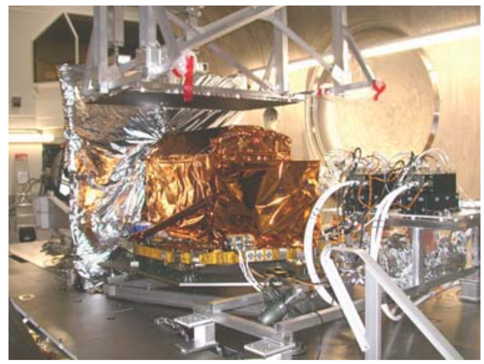

Figure 29 : T/V test configuration

4.4 Performance test results

The measurements performed under thermal vacuum conditions have demonstrated the full compliance to the performance requirements. The following sections gives some test results concerning CTF and SNR test results.

◆ ***CTF measurements***

The following curve gives, for the panchromatic band, the CTF values obtained for the nominal operation thermal case.
Besides this nominal case, it has been verified that the performances can be maintained in the +/- 200µm focussing adjustment range.

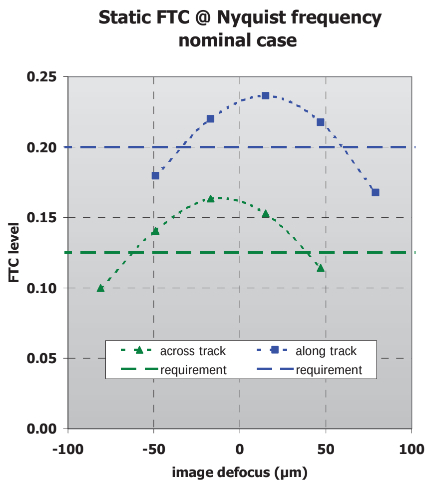

Figure 30: CTF around best focus

◆ ***SNR measurements***

The following figure summarizes the SNR results (the min values are based on the less performing pixels)

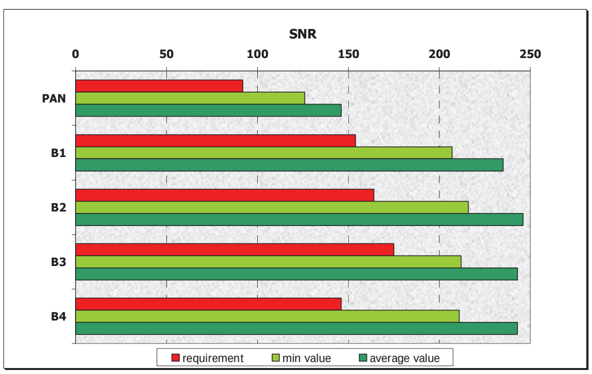

Figure 31: SNR performance results

5 OVERVIEW OF THE ACHIEVED PLANNING

The main program phases can be summarized as follow:

T0 : 15/12/99
T0 - T0+5 : Preliminary design phase
T0+5 - T0+17 : Design consolidation
T0+17 – T0+23 : Support programs
T0+23 - T0+29 : Flight Model assembly
T0+29 – T0+33 : Flight model qualification tests

6 CONCLUSION

With this program, EADS-Astrium entered the export market with the first worldwide contract for a high-resolution civilian observation mission.
The main challenge, successfully achieved, was to combine an innovative design to a tight development schedule.

ROCSAT is to be launched in April 2004 on a OSC TAURUS launcher.