THE INFRARED IMAGING RADIOMETER FOR PICASSO-CENA

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RESUME

Les détecteurs microbolomètriques apparaissent sur le marché depuis quelques années, notamment aux Etats-Unis, dans le but de proposer des caméras à faible coût pour application militaires et civiles.

Des applications spatiales de cette technologie sont envisagées grâce aux réductions de coût qu'elle peut permettre.

Parmi les quatre instruments de la charge utile de PICASSO-CENA, le Radiomètre Imageur Infrarouge (IIR) utilise cette technologie. La camera infrarouge développée pour l'instrument IASI constitue le cœur de l'IIR.

Le but de ce document est de rappeler les objectifs de la mission PICASSO-CENA, de décrire l'architecture de l'instrument et donner ses principales caractéristiques et, enfin, de décrire son état de développement.

ABSTRACT

Microbolometers are infrared detectors of an emerging technology mainly developed in US and few other countries for few years. The main targets of these developments are low performing and low cost military and civilian applications like survey cameras.

Applications in space are now arising thanks to the design simplification and the associated cost reduction allowed by this new technology.

Among the four instruments of the payload of PICASSO-CENA, the Imaging Infrared Radiometer (IIR) is based on the microbolometer technology. An infrared camera in development for the IASI instrument is the core of the IIR.

The aim of the paper is to recall the PICASSO-CENA mission goal, to describe the IIR instrument architecture and highlight its main features and performances and to give the its development status.

1. INTRODUCTION

The Pathfinder Instruments for Cloud And Spaceborne Observations-CENA mission is part of the NASA's Earth System Science Parthfinder (ESSP) program. It is planned for three years and is being developed within the framework of collaboration between NASA, CNES, Hampton University and Pierre Simon Laplace French Institute. The payload, on a PROTEUS platform, includes a Lidar, a Wide Field Camera and an Infrared Imaging Radiometer (IIR). These instruments will provide unique information on the global distribution and properties of aerosols and clouds leading to improved capabilities for predicting climate and climate change. The satellite will be flown, in mid 2003, in formation with EOS PM (Aqua), CloudSat and Parasol.

The required radiometric performances for the IIR as far as the geometrical sampling appear to be reachable by using the microbolometer technology. A compact low consuming camera based on this technology, has been previously designed to be implemented in the IASI instrument to meet comparable objectives as those of PICASSO-CENA. This camera is reused in the IIR.

2. PICASSO-CENA MISSION GOAL

The IIR will provide calibrated infrared radiances at three wavelengths, which will be combined with daytime and nightime lidar measurements to retrieve radiative and microphysical parameters of clouds. Measurements in the 8 to 12 microns spectral domain are classically used to infer cloud particle size. Present analyses of simulations and measurements show that the use of channels at 11 and 12 microns is well suited for retrieving small particles, whereas the use of 8.5 and 12 microns is more sensitive to larger particles. The IIR 3 channels have been chosen to optimize the discrimination of scattering and absorption properties by complex crystals and allow to differentiate between spheres and hexagonal shapes.

3. IIR DESCRIPTION

3.1. General description

The Imaging Infrared Radiometer (IIR) for PICASSO-CENA is an infrared three channel broadband radiometer which is based on the use of an infrared microbolometer camera.

The basic function of the IIR is to provide Earth images in three spectral bands at a period of time of 8s.

The radiometric requirements are such that complementary functions need to be implemented in the instrument :

- an in-flight calibration is required to cope with environmental and ageing instabilities,

- three spectral bands have to be analysed in the overall spectral range 8.5 – 12.4 µm.

The in-flight calibration is performed using measurements on the deep space (offset correction) and on the internal black body (gain correction).

The sequencing of the measurements is optimised to :

- minimise the time delay between the three Earth images and, then, maximise the overlapping of the images,
- minimise the mechanisms operations to reduce attrition and power consumption.

The sequencing is described on figure 1. It shows that, during a cycle of 40s, the deep space is measured 4 times, whereas the black body is only measured once. The reason is that gain and offset have not the same temporal evolution, the latter being more sensitive to thermal variations and requiring correction at a higher frequency.

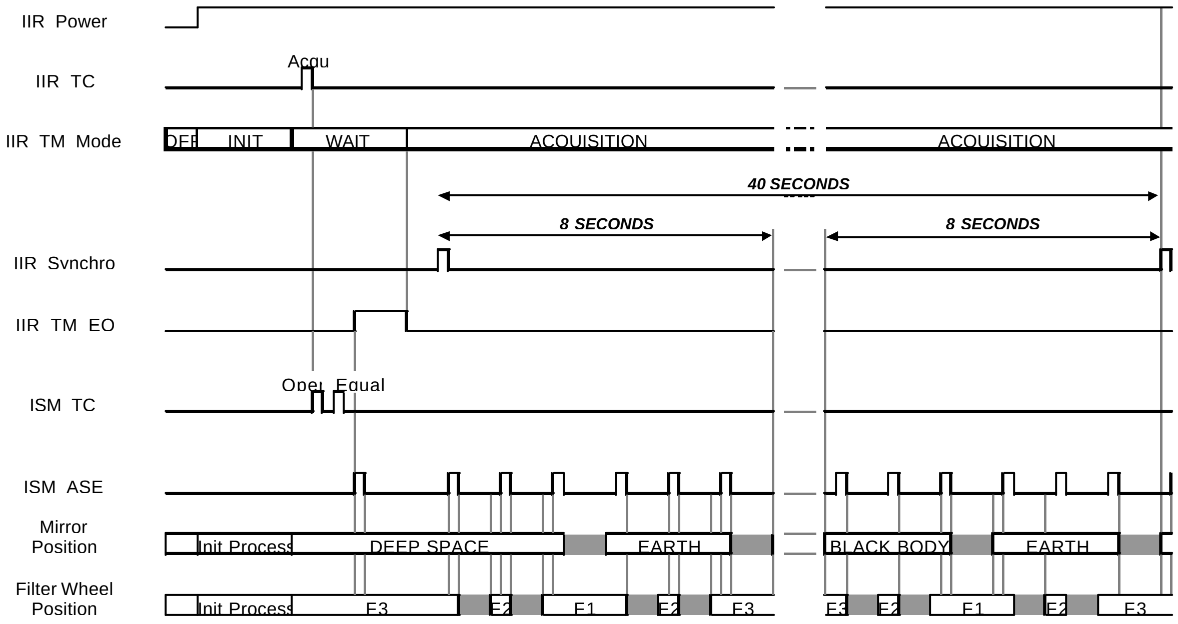


Fig. 1 - IIR sequencing

The IIR is composed of (figures 2 and 3) :

- an Imaging Sensor Module (ISM), derived from the camera developed for IASI. The optics is completely redesigned because of the very different constraints. Radiator and sun shield are also modified to adjust the design to the IIR specific thermal interfaces,

- a rotating filter wheel holding 3 filters placed in front of the ISM,

- a black body for in-flight calibration,

- a folding mirror mounted on a mechanism to allow Earth, black body and deep space sighting,

- an electronic control box which supplies, commands and controls the IIR sub-assemblies and interfaces with the payload,

- a mechanical structure that support all above sub-assemblies and is fixed to the payload.

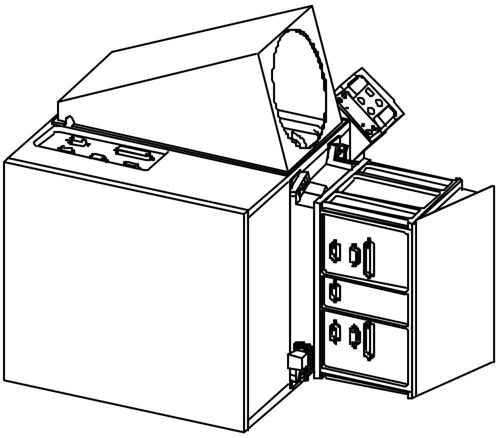


Fig. 2 – IIR general view

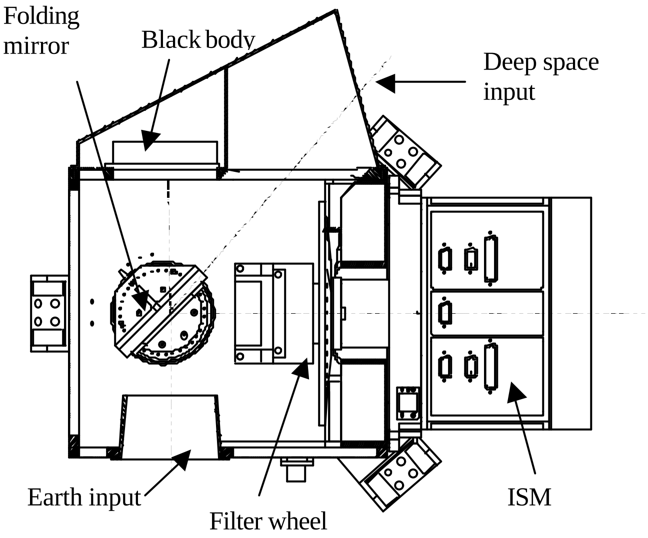


Fig. 3 – IIR detailed view

3.2. ISM camera general description

The main functions of the ISM are :

- to provide 64x64 images in a 90x90 mrad field of view,
- to operate in 3 channels in the 8.5-12.4 µm spectral band,
- to achieve a Noise Equivalent Temperature Difference (NETD) figure of 0.5 K for a scene temperature of 210 K in each channel,
- to provide images at a period of 216 ms.

An overall view of the ISM is shown on figure 4. It is composed of :

- an objective,
- a microbolometer detector array,
- two (nominal and redundant) video processing 12 bit channels,
- two (nominal and redundant) DC-DC power converter including the detector active thermal control,
- a switch for transfer from nominal channel to redundant one.

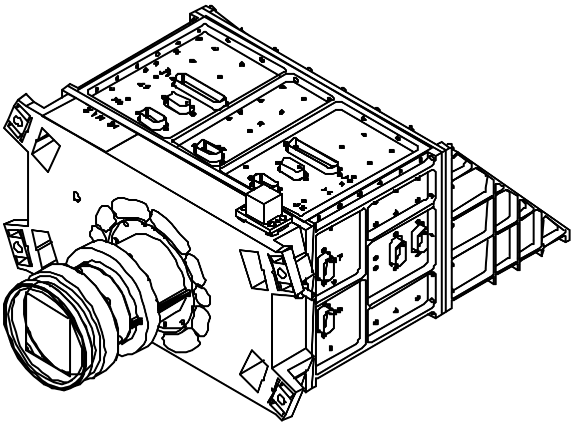


Fig. 4 – ISM view

3.2.1. Detector description

The detector is an uncooled infrared sensor assembly U3000A manufactured by BOEING.
The U3000A sensor assembly incorporates advanced monolithic vanadium oxyde microbolometer technology active in the 8-14 µm wave band.

It is a standard product that includes :

- a thermo-electric cooler for temperature stabilisation,
- nominal and redundant temperature sensors,
- a getter,
- an antireflection coated germanium window,
- a rugged vacuum package.

The U3000A sensor assembly offers 320 lines per 240 rows, 64x64 of which only are used in ISM. The pixel size is 51x51 µm².

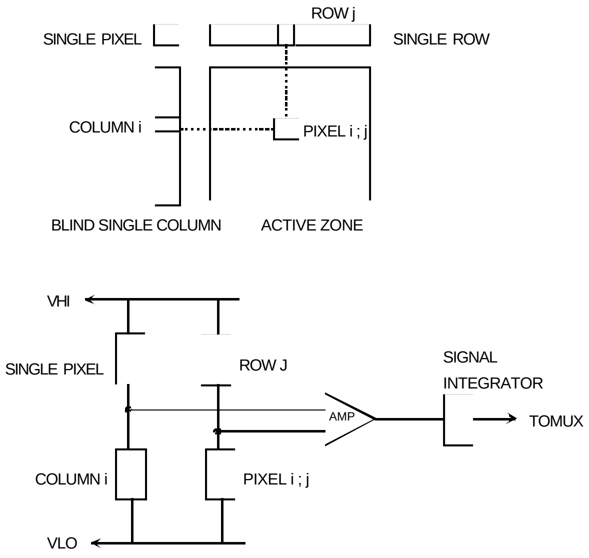
The detector internal structure is described on figure 5. It is based on a reference bridge concept that provides :

- offset compensation,
- resistance change due to operating temperature drift rejection.

The bridge differential voltage is proportional to the pixel temperature increase under illumination. It is amplified and integrated to adjust gain and noise bandwidth.
Pixel reading is made by means of a pulsed current to minimise power and temperature increase of the pixel.

The detector functional structure is shown on figure 6.

All pixels of a line are processed simultaneously by 320 integrators and sample & hold device in parallel. The sequential address mode imposes to read all the array even if a limited zone is used. To minimise the overall readout time in the ISM, two rates for the pixel acquisition are used according to the pixel location.



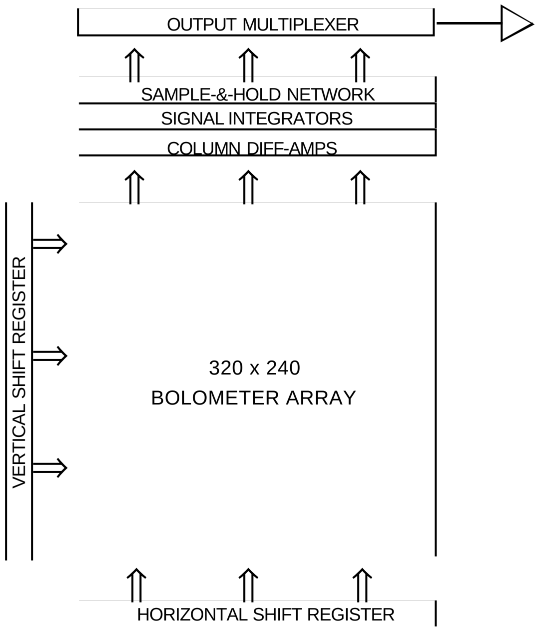


Fig. 5 - Detector internal structure

Fig. 6 – Detector functional structure

3.2.2. ISM objective design

The design constraints are the following :

- it must cope with the mechanical interface constraints induced by the existing IASI camera,
- the pupil size has to be as large as possible to collect the maximum flux to compensate the narrow spectral bands and the low scene temperature to be measured,
- the spectral range has to be wide enough to cover the three bands in the range 8.5-12.4 µm while offering a good MTF.

The optimisation result leads to the optics structure shown on figure 7. It includes four lenses, one being in germanium and including an aspheric surface, the three others being in ZnSe.

Each lens is maintained by a titanium barrel, with silicon bonding. All barrels are machined after mounting of the lens to perform an accurate adjustment and meet the image quality requirements. The mechanical tolerances are in the range of few microns.

The characteristics of the optics are summarised in table 1.

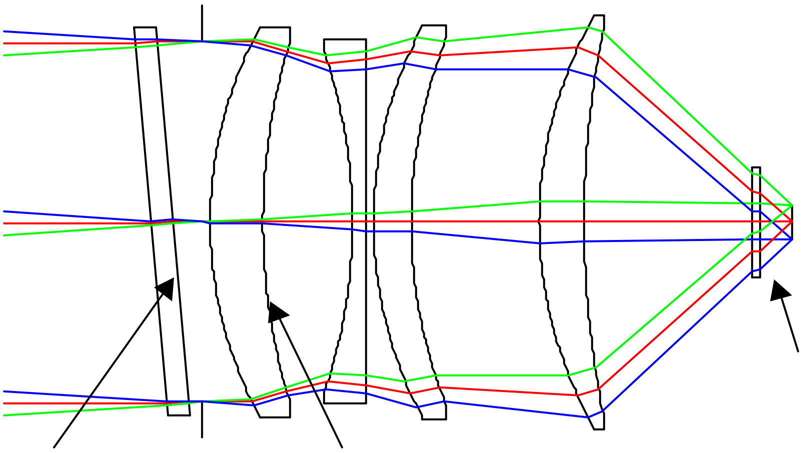


Fig. 7 – Objective design

	Characteristics
Spectral bandwidth	8.5-12.4 µm
Focal length	35.9 mm
Optics speed	F/0.75
FOV	90x90 mrad
FTM	> 0.5
Distortion	< 0.23 mrad

Table 1 – Objective characteristics

3.3. IIR mechanical architecture

The general architecture of the IIR is driven by the use of an existing camera (ISM) which is the core of the instrument.

Four other main subassemblies have to be laid out :

- the filter wheel,
- the folding mirror,
- the control box.,
- the black body.

The main structure is made of a baseplate that attach the IIR to the payload, and a cornerplate that links the ISM and the baseplate. Both plates are made of aluminium. The baseplate directly supports the folding mirror and the filter wheel.

Flexible links are designed to minimise thermo-elastic loads at both IIR-payload and ISM-IIR interfaces.

Four sides close the IIR and support subassemblies which do not require accurate positioning : control box, black body, space shield, MLI, wires and connectors.

The ISM incorporates three main subassemblies :

- the optical one, including the objective and the detector. Mechanical parts are made of titanium to cope with the lenses thermo-mechanical characteristics. A shim-plate is adjusted to focus the detector with respect to the optics. A transversal adjustment of the detector is also possible to select the operational area and minimise the number of non-operable pixels.
- the electronic box, including electronic boards and radiator. The main mechanical parts are made of aluminium alloy for its mass and thermal conductivity. The electronic boards are mounted in frames used as stiffeners and thermal drains. Surface Mounted Technology (SMT) is extensively used.
- the interface baseplate made of titanium that holds the ISM on the instrument. This part determines the dynamic behaviour of the ISM. It is optimised to provide mechanical stiffness and thermo-elastic flexibility.

The mechanisms shall meet the following requirements :

- accurate mirror positioning (0.01 arcdeg) for earth sighting,
- coarse mirror positioning for deep space and black body sighting,
- coarse positioning for the filters.

To optimise the development, common solutions are used for both mechanisms : motor, ball bearings, lubrication, position sensor…

Stepping motors are used to have a simple locating control. The motorization margin is sufficient to avoid any step jump.

The accurate position of the folding mirror is obtained by means of a hard stop on which the mirror is pressed. A double stop device is used :

- soft stop : to provide a precise control of the rotation speed just before the impact on the final stop and, then, minimise the transmitted torque,
- hard stop : to provide the accurate position.

3.4. IIR thermal architecture

The drivers for the thermal design are again the constraints imposed by the use of the ISM with minimum redesign of it.

The constraints are summarised hereafter :

- the ISM detector temperature has to be maintained around 20°C with a very high stability to meet the radiometric requirements,
- the ISM objective temperature has to be maintained constant to preserve the image quality and to minimise the straylight variation,

- the IIR structural parts has to be stable enough to provide the mechanical stability and to minimise the straylight variation,
- the IIR interface temperature may vary in the range 20°C ± 5°C,
- the radiative exchanges between the IIR and the satellite including its solar panels, and the sun and the earth have to be taken into account .

To minimise the camera redesign, the ISM remains relatively independent of the rest of the IIR :

- the radiator of the ISM provides the cold source for the regulation of the detector,
- this radiator evacuates the ISM electronic power towards space,
- an internal thermal P type control line is implemented in the ISM for the detector regulation,
- the ISM is isolated from the IIR by means of its fixation tabs.

A thermal control line, coming from the IIR control box, allows to regulate the objective.

The thermal stability and homogeneity of the IIR structural parts is obtained thanks to :

- the use of a highly conductive material (aluminium),
- the use of a specific radiator to evacuate the IIR power towards space,
- a thermal control of this radiator to minimise its temperature variations all along the orbit.

The black body is not specifically thermally controlled, but its temperature is accurately measured during the image capture for a better correlation. The black body radiance is calibrated on ground versus its measured temperature.

Except both radiators and the ports for earth and deep space sighting, all parts of the IIR are covered with Multi-layer insulation (MLI) for isolation purpose.

This design allows to meet the requirements (detector temperature stability better than 1 mK over 80s, objective temperature of 20°C ± 1°C) with a power consumption lower than specified (22 W). The IIR inner parts temperatures are quite stable and homogenous (order of magnitude of 1°C).

3.5. IIR electronic architecture

The general electronic architecture of the IIR is described on the figure 8. A large part of the electronics is included in the ISM and is identical to that of the IASI camera, except the redundancy which is not used in the IIR. The second main subassembly is the control box that interfaces with the payload and control all other parts of the IIR.

The ISM electronic functions shown on figure 9 are as follows :

- DC-DC power conversion,
- accurate thermal control of the detector,
- stable and noiseless detector bias voltages,
- video signal processing,
- sequencing and interface control. It is built around a FPGA type sequencer associated with two RAMs for parameters and current image storage,
- telemetry.

The salient points of the ISM electronics are :

- detector thermal control : due to the large dependency of the output signal with the temperature, a temperature stability of the chip of 1 mK over 80s is required. An analogue regulation is chosen to avoid sampling noise and because of its simplicity with respect to a digital one : lower active parts number, lower computation resources. It is a proportional type that has been designed to cope with the thermistor time constant (~10s). The simulated and measured performances (0.8 mK) are compliant with the requirement.

- detector bias voltages : this is the more critical function of the electronics. As standard regulators cannot meet the noise and stability requirements, specific circuits based on the use of very precise and stable voltage reference have been designed. The adopted structure provides a low bandwidth and a good behaviour to charge variations. An integrated noise performance of 2.7 µV in the 0.1 Hz – 10 MHz range has been achieved. The thermal drift at the regulator output is of 50 µV/°C.

- analogue video signal processing : the video processing chain has to be designed to cope with the low level useful signal range (0-100 mV) whereas the pixel offset dynamic is very large (0-4 V). Two main functions have then to be realised :
    - a correction of the individual pixel offsets,
    - an amplification of the resulting video signal.

  At the beginning of the operation of the camera, an equalisation process is performed by measuring an uniform scene to determine and memorise the offset value of each pixel.
  At each image capture, an offset correction is performed by means of a 8 bit DAC that reduces the Fixed Pattern Noise (FPN) from typically one volt to few millivolts.
  After offset correction, the video signal is amplified and digitised.
  An additional device allows to avoid saturation of the amplifier during readout of the unused pixels.
  With a chain gain value of 3, the noise level of the electronics is lower than 100 µV and, then, negligible compared to the detector noise.

To improve the NETD performance, 5 frames are taken during an image period (216 ms). The first one is not processed nor transmitted since it is dedicated to thermal settling. The 4 following frames are averaged by the FPGA.

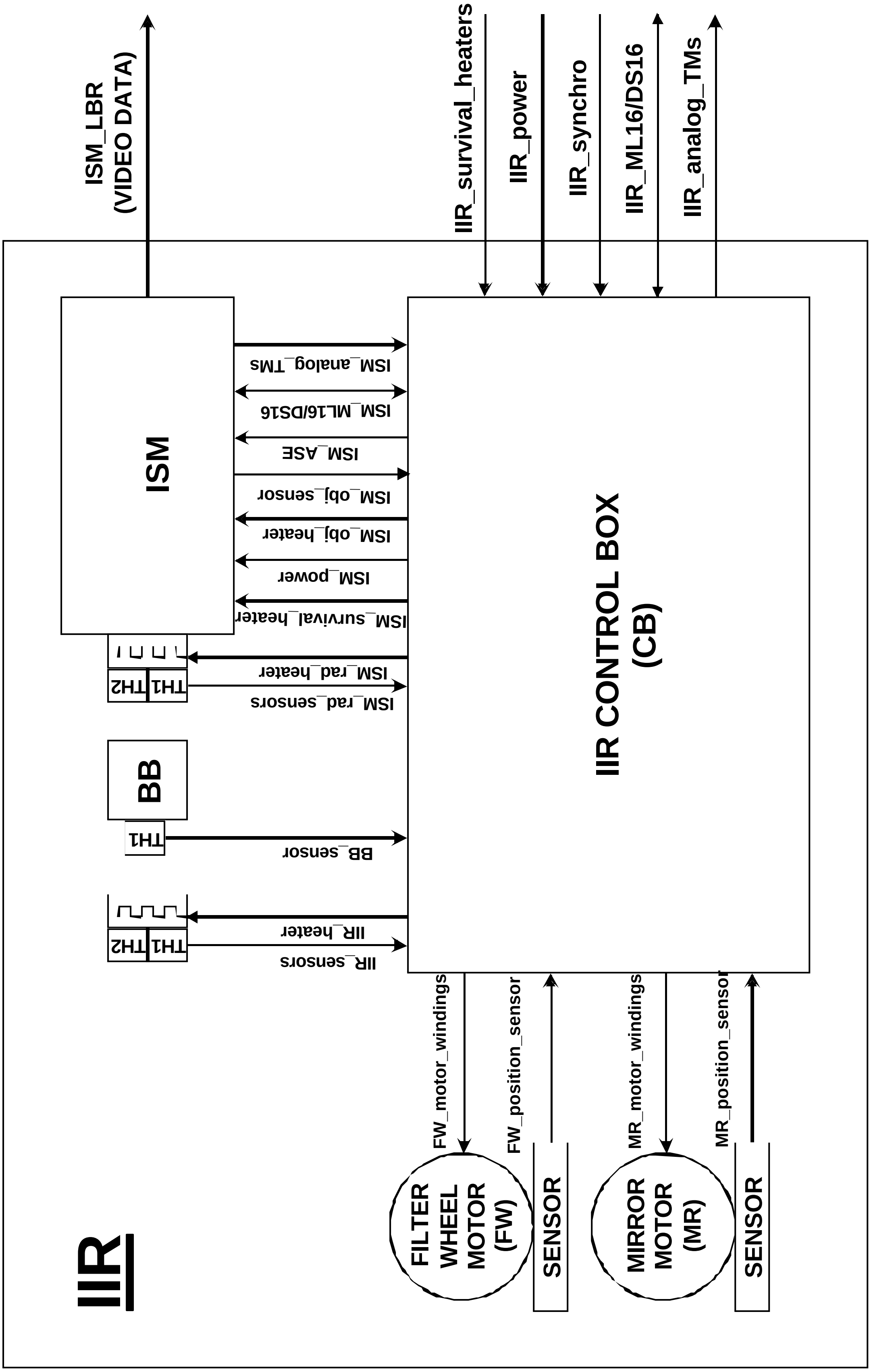


Fig. 8 – IIR electronic architecture

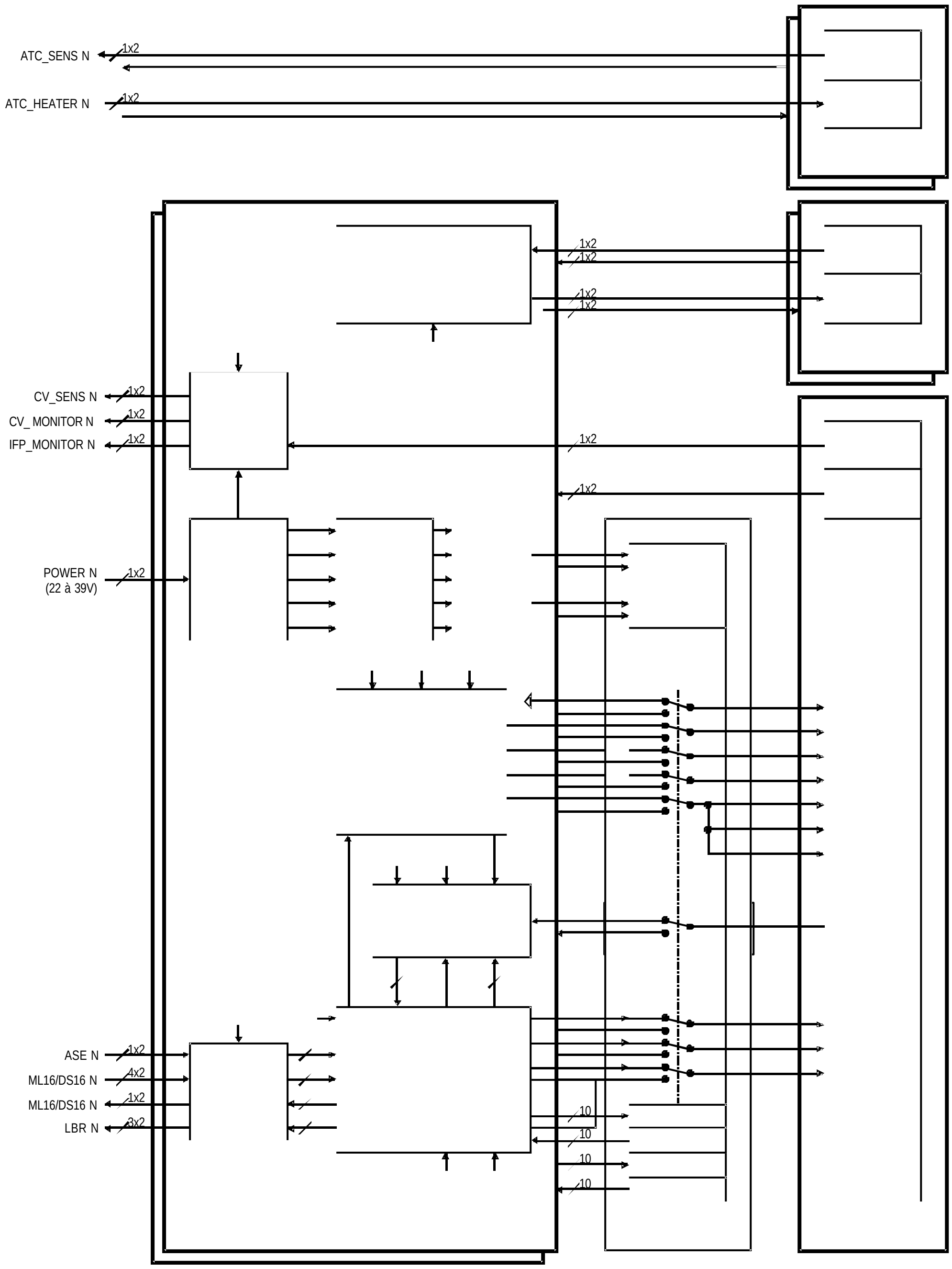


Fig. 9 – ISM electronic architecture

The control box manages :

- the IIR synchronisation,
- the IIR telecommand and control,
- the mechanisms command,
- the IIR thermal control.

It includes :

- a DC/DC converter,
- 3 thermal control loops,
- 2 motor interfaces, that include the supply and command of the stepper motors and position sensors. The motors control signals are optimised to reduce the mechanical perturbations transmitted to the payload and the satellite : acceleration and deceleration phases are introduced in each movement to obtain regular speed variations of both mechanisms,
- a digital sequencer made around a FPGA that controls and synchronises both mechanisms and ISM operations.

3.6. IIR CHARACTERISTICS

The IIR main performances and budgets are given in table 2.

	Characteristics
Field of view	90x90 mrad
Spatial resolution	64x64 pixels
Spectral band width	B1 : 8.5-9.3 µm - B2 : 10.1-10.9µm - B3 : 11.6-12.4 µm
Optics speed	F/0.75
Image frequency	4.6 Hz
NETD	B1 : 0.8 K - B2, B3 : 0.5 K @ 210 K
Absolute accuracy	1 K
Blind pixels	< 2 %
MTF	0.2 (including smearing)
Detector temperature stability	< 1 mK
Volume	450x700x300 mm^3
Mass	21 kg
Power consumption	22 W
Power supply	22 to 37.5 V
Video output data	12 bit
Operating temperature	20°C ± 5°C (mounting plane interface)
Storage temperature	-25°C ; +65°C
Random vibrations	20 grms
Sine vibrations	20 g [20-100 Hz]

Table 2 –IIR characteristics

4. PROGRAMMATIC ASPECTS

The camera design is now completed in the frame of IASI and is supported by breadboards :

- a structural model has shown the satisfactory behaviour in vibration environment,
- a functional breadboard has been developed to validate the electronic design and performances.

It has also been used to demonstrate the temperature stability of the detector.

A pre-evaluation program has been conducted on the detector to demonstrate its suitability to the spatial environment (irradiation and vibrations).

The IIR Preliminary Design Review held in June 2000 has proved that the performance and budgets objectives are met.

The IIR flight model will be delivered in early 2002.

ACKNOWLEDGEMENTS

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The design of the IIR mechanisms is derived from an existing one previously developed by CNES.