A new test facility for the E-ELT Infrared Detector program

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ABSTRACT

During the development of the VLT instrumentation program, ESO acquired considerable expertise in the area of infrared detectors, their testing and optimizing their performance. This can mainly be attributed to a very competent team and most importantly to the availability of a very well suited test facility, namely, IRATEC.
This test facility was designed more than 15 years ago, specifically for 1K x 1K detectors such as the Aladdin device, with a maximum field of only 30 mm square. Unfortunately, this facility is no longer suited for the testing of the new larger format detectors that are going to be used to equip the future E-ELT instruments. It is projected that over the next 20 years, there will be of the order of 50-100 very large format detectors to be procured and tested for use with E-ELT first and second generation instruments and VLT third generation instruments.
For this reason ESO has initiated the in-house design and construction of a dedicated new IR detector arrays test facility: the Facility for Infrared Array Testing (FIAT). It will be possible to mount up to four 60 mm square detectors in the facility, as well as mosaics of smaller detectors. It is being designed to have a very low thermal background such that detectors with 5.3 µm cut-off material can routinely be tested.
The paper introduces the most important use cases for which FIAT is designed: they range from performing routine performance measurements on acquired devices, optimization setups for custom applications (like spot scan intra-pixel response, persistence and surface reflectivity measurements), test of new complex operation modes (e,g, high speed subwindowing mode for low order sensing, flexure control, etc) and the development of new tests and calibration procedures to support the scientific requirements of the E-ELT and to allow troubleshooting the unexpected challenges that arise when a new detector system is brought online. The facility is also being designed to minimize the downtime required to change to a new detector and then cool it down, ready for testing.
The status of the opto-mechanical and cryogenic design is also described in detail, with particular emphasis on the technical solutions identified to fulfill the FIAT top level requirements.
We will also describe how the FIAT project has been set-up as a training facility for the younger generation of engineers who are expected to take over the job from the experienced engineers and ensure that the lessons learnt in so many years of successful IR instrumentation projects at ESO are captured for this next generation.

Keywords: Cryostat, cryogenic instrument, Infrared instrument, Infrared detector, test facility

1. INTRODUCTION

The ESO ELT is starting to enter in its real construction phase and together with it the development of the instrument suite. Most of the first generation of instruments are Infra Red instrument accommodating in most of the case multiple detectors. It is clear that the old test facility built for the qualification of smaller 256 square detectors is absolutely not suited for the task. The responsibility to provide fully characterized IR detectors remaining on the detector team of ESO, the decision was then taken to design a new test facility. Taking into account the large effort involved to the design such test cryostat, it is very important to design a system with a useful life time of at least 15 years. The very high number of detectors to be tested has a large impact on the design and more especially on the operation mode of the facility. The present paper shows the general concept and some details of the design of the sub-systems.

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2. MAIN REQUIREMENTS

The following section lists the various requirements which have been defined in order to make from FIAT the ideal test facility for the infrared detectors of the E-ELT era.

2.1 General requirements

- The system shall be designed to allow deployment of the arrays for use in their final operating environment at their peak (optimized) performance ("science ready").
- The system shall be designed to fit into the available space of the designated IR detector lab.
- The system shall be fully tested and ready for use within 3 months after delivery of the first detector for the MOONS project (currently foreseen for Q1/ 2016).

2.2 Functional requirements

- The system delivers a FOV of 61.44 x 61.44 mm (corresponding a Teledyne H4RG detector). It shall provide the necessary space for connectors and cryogenic electronics. (Goal: the system shall allow mounting larger arrays up to 2x2 H4RG mosaics - in this case only part of the array area is tested).
- The system shall be designed to test IR arrays in the wavelength range 0.8-5.5 mm (Goal: extend to the blue range to 0.5 mm). The 5.5 upper wavelength limit is set to ensure that the test bench is sensitive over the cut-off wavelength of the detector by at least 5%.
- The system shall be used to perform full detector characterization and optimization of different cut-off wavelength IR arrays (e.g. 1.8, 2.5 and 5.3 mm) operated in the temperature range (20-150 K) as close as possible to nominal operating conditions and modes.
- The system shall be compatible to ESO standards.
- The system shall offer easy and safe access to the detectors, and sufficient space for cryogenic proximity electronics, care should be taken that any cryogenic pre-amplifiers do not introduce photon background.
- One complete detector exchange cycle (warm-up, opening, dismounting the detector, mounting a new detector, pumping, cool-down) should be possible in 5 working days.
- The system shall be designed to include a cold pupil and a warm object plane, located outside the entrance window, that is conjugated to the detector plane.
- The system shall have provisions for at least 20 filter positions in at least two separate wheels one for band-pass and one for neutral density filters. (Goal: the wheels shall be easily accessible for filter swaps)
- The system shall have provision for an Fe^{55} or Cd^{109} radioactive source to measure impulse response and detector response to calibrated localized source.
- The system shall have one mechanical function with at least four positions in front of the detector to accommodate the following: A dark position for dark current measurements, one position for surface reflectance tests, an open position corresponding to the size FOV.
- The system shall have provision for calibrated flux adjustments independent of integration time.
- The system shall be delivered with a standard engineering GUI to control its functions (NGC excluded). Archiving of raw and reduced data via a standard I/F to the ESO archive shall be supported.
- The system design shall minimize the chances of detector contamination with foreign material during mounting, dismounting, and operations.

2.3 Performance requirements

- The system optical performance shall be homogenous over the FOV
- The system shall be designed to allow ultra-low background measurements, that is, in dark conditions, the background radiation falling onto the array shall be ≤ 10-3 photon/pix/sec.
- The system shall have a well-defined etendue AΩ to allow absolute flux calibrations and (e.g. coating) tests to better than 5% (goal 3%) everywhere in the FoV
- The system shall have an on-axis spot-projector suitable for intra-pixel measurements in J-band or shorter. In the central 1 mm (TBC) of the FOV the projector shall deliver 90% of the energy in 7.5 um diameter for integration times longer than 10 msec

3. OPTICAL DESIGN

A number of attempts has been required prior finding the adequate final optical design presented in figure 1. A few dioptric solutions have been rapidly dropped because of the complexity and risk linked with the mounting of large lenses at cryogenic temperatures. A classical Hoeffner system was hardly feasible due to the large field.

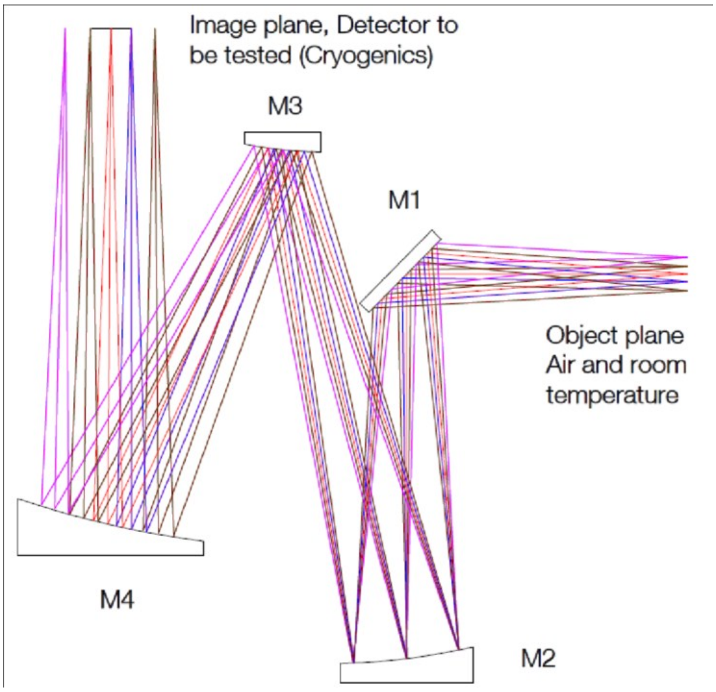

Figure 1. Basic optical design.

Finally a pseudo Hoeffner system has been selected where the last mirror is a sphere and the two previous ones are aspheric with conical constant. Mirror 1 is a simple flat mirror used to fold the beam and then provide an easily accessible external focal plane. Table 1 give a detailed optical characteristic of the 4 main mirrors. The mirrors are manufactured in Al6061 using diamond turning. In order to get the required micro-roughness of 5 nm rms imposed by the short wavelength, the mirror will be post polished. For this the mirror are coated with a 60µm layer of nickel which is refigured by diamond cutting before final polishing.

Table 1. Characteristic of the mirrors.

Mirrors	**Shape**	**Radius of curvatures, (mm)**	**Useful diameter, (mm)**	**Beam foot print, (mm)**	**Off axis Distance, (mm)**
M1	Flat	Infinity	76 x 62	50 x 36	-
M2	Conic (CC=0.9690)	538.4 CC	85	83.2	65.00
M3	Conic (CC=2.0054)	321.7 CV	56	24.2	31.76
M4	Sphere	757.0 CC	140	23.9	

Figure 2 shows the complete optical schematic of the FIAT test facility. We can recognize the 4 mains mirrors already described above. We see also the 2 set of 10 filters which equipped the two filter wheels. A plan parallel plate of CaF_2 is used as window in order to seal the vacuum chamber. A small inverted Cassegrain system machined in a single piece of BaF_2 is used as magnification lens right before the detector. This lens which allow to get an image of the order of a few microns is inserted in the beam for high accuracy scanning. This mode is used to analyze the local punctual response of the detector and more specifically in the pixel to pixel transfer region. The lens being inserted in the beam the image can be scanned over the detector over a few microns by moving the external source which is provided by an optical fibre.

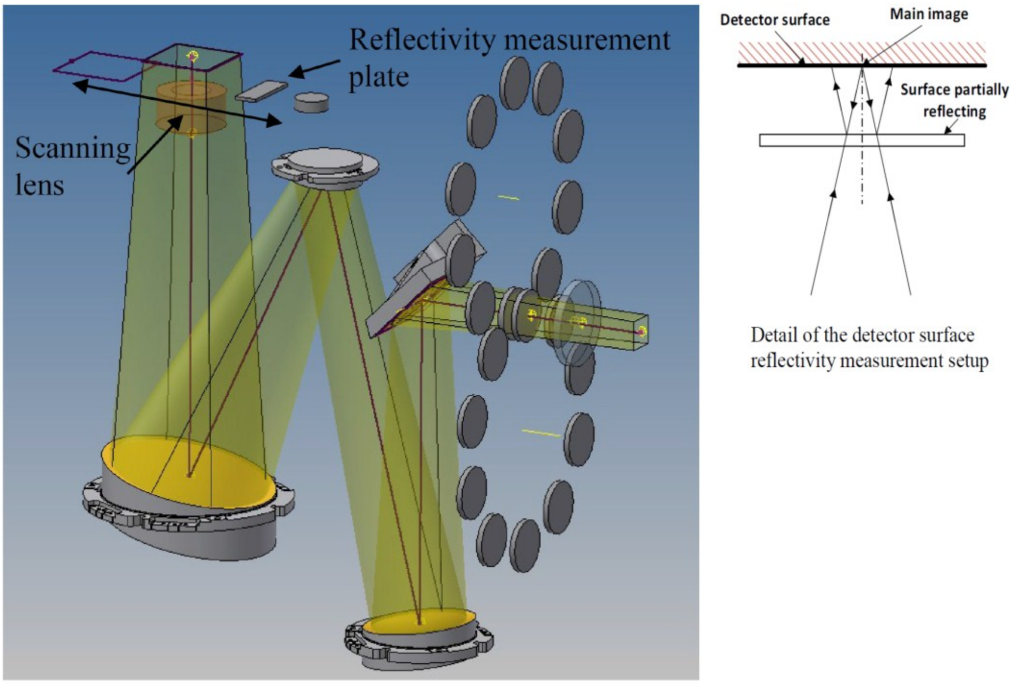

Figure 2. Overall optical schematic

The last component is a thin plate of CaF2 which has its second surface partially reflecting. When this plate is inserted in the beam, integrating and analyzing the halo of light created around the main image allows to determine the reflectivity of the detector surface (Fig.2 right detail).

4. CRYO-VACUUM DESIGN

4.1 Vacuum design

The vacuum system is designed based on the standard vacuum system of VLT instruments. The vessel is evacuated via a combination of dry pre vacuum pump and magnet levitation Turbo-Molecular Pump. The ESO standard includes a 500l/s TMP which is extremely powerful for this rather small instrument and then allows reaching a operational pressure after less than one hour of pumping. The system will be fitted with the conventional safety features in order to ensure safe handling both for the operators and for the detectors.

4.2 Cryogenic design

The cryogenic design of FIAT benefits directly from the long experience gained at ESO with the construction of a number of Infrared instruments. The strategy follows directly the architecture used for most of the major VLT instruments. The optic assembly is cooled using a continuous flow of liquid nitrogen. During operation the instrument is kept at cryogenic operation using a Closed Cycle Cooler Coolpower 10MD from Leybold (ESO VLT standard). Two operating modes are defined depending of the detector which is tested. In case of a K band detector the temperature is stabilized at 80K. This allows to have rather short cool-down times only limited by the cooling rate of the detector. In the case of an L or M band detector the optic assembly is cooled down to 65K. The change of mode is executed, when the instrument is opened to install the detector, adding some thermal connections between the cold structure and the first stage of the cold head. This of course will extend the cooling time by a few hours.

The cooling of the detector is provided by the second stage of the cold head. A 3000g copper bar has been introduced in the cooling chain. This is what is called the cooling bank. This allows two manage safely three different critical cases. First it is used to limit physically the cooling rate of the detector and then avoid any damaging stress. Secondly it allows to keep the detector at operating temperature (without CCC running) for a period of 30 minutes. This allows performing very sensitive measurement without any source of vibration. Finally this is the component which is heated in order to pre-select the operating temperature of the detector and also during warm-up at the end of a test campaign. This minimizes the changes on the detector temperature controller and avoid having powerful heater close to the detector.

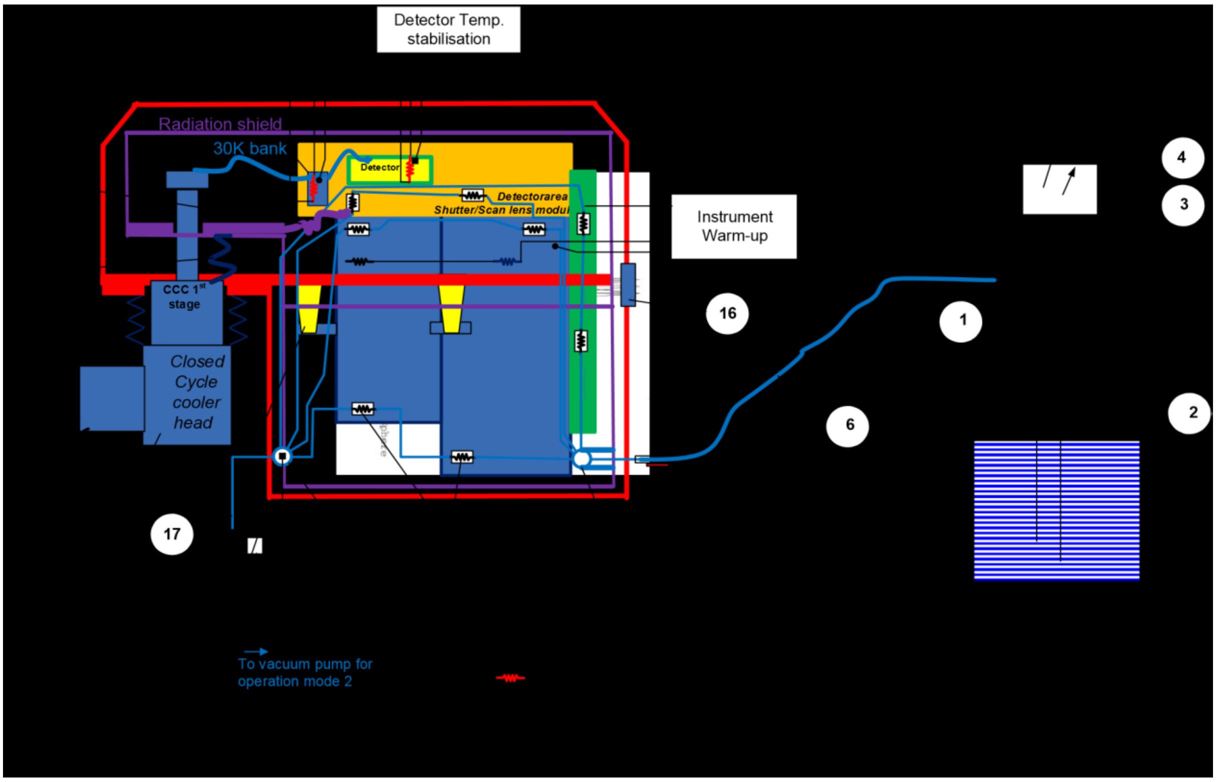

Figure 3. Cryogenic schematic, 1. LN2 tank, 2. Pressure release valve, 3. Manometer, 4. Over pressure safety valve, 5. LN2 level sensor, 6. LN2 transfer line, 7. LN2 line splitter, 8. Heat exchangers, 9. LN2 line collector, 10. LN2 regulation valve, 11. Optic assembly cooling braid, 12. Shutter cooling braid, 13. Vibration damper bellows, 14. Insulating supporting of the cold optic assembly, 15. CCC system, 16. Window, 17. Safety release valve, 18. LN2 line detection system

4.3 Cryo-vacuum operations

The complete cryo-vacuum operation is controlled via a Siemens PLC. Most of the operations are automatized in order to gain time. After closing the facility with a new detector to be tested, the operator (a detector specialist) start the cryo-vacuum operation. This will happen most probably in the evening after a day used to change the configuration. The operation is started launching the sequence with the touch panel and connecting a pressurized LN2 supply tank. Then the system will evacuate the test facility and automatically start the LN2 pre-cooling. The rest of the sequence will follow automatically with starting the CCC until stabilization of the temperature is reached. Measurement can start on the following morning. A high level of security is built in the system in order to allow this kind of automatism.

5. OPTO-MECHANICAL DESIGN

5.1 Cold optic assembly

Like every infrared instrument FIAT opto-mechanics is cooled to cryogenic temperature. For this reason it is important to have a rather compact structure which supports the optic and the various sub-systems. In the case of FIAT the cold assembly is divided in 4 main sub-systems. The optic assembly which is a structure composed off two sections machined directly in Al 7075 cryogenically aged in order to have a thermal behaviour as close as possible to the one of the mirror. The optic assembly supports the other modules, in front the filter wheel system, on top the detector environment with the slide sub-system inserted in between. Every sub-system is referenced using a 3 pin/slot system. Every connection plan is completed with a labyrinth in order to minimize as much as possible the level dark current.

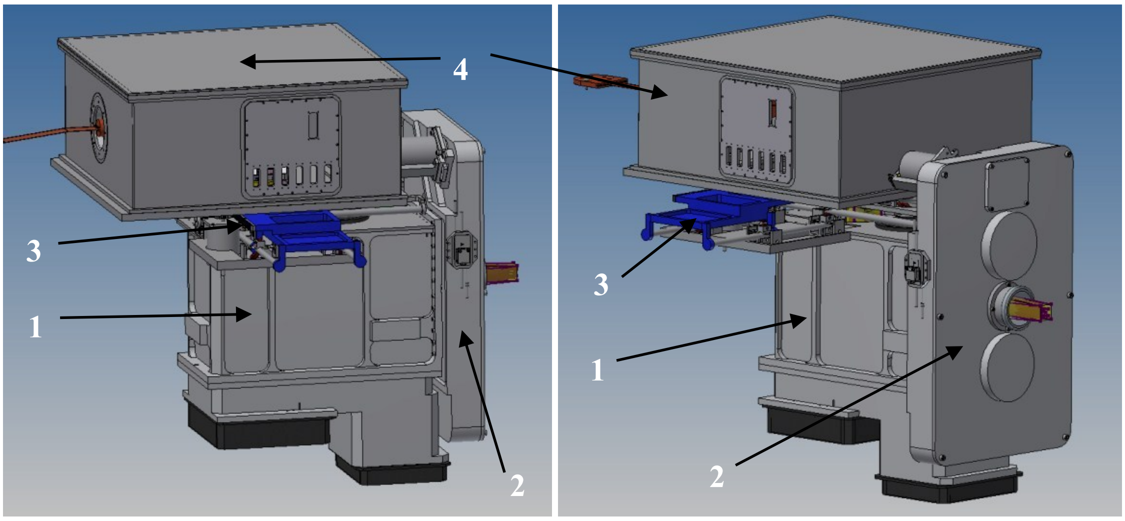

Figure 4, Cold optic assembly; 1. Optic assembly structure, 2. Filter wheel assembly, 3. Slide system, 4. Detector environment

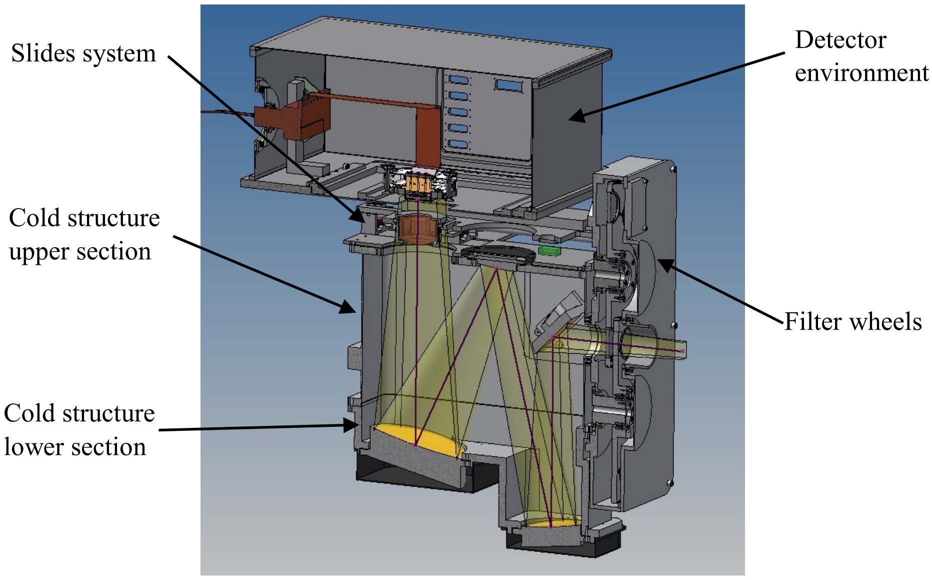

Figure 5. Cold optical assembly.

Figure 5 shows a cut through the symmetry axis of the instrument. We can easily recognize the 4 mirrors directly attached on the two sections of the optic support structure.

5.2 Filter wheels

Figure 6 shows the design for the filter wheels. The configuration and scheme of this sub-system is defined in order to fulfil the technical requirements. This includes the use of two filters at the same time (Band path and neutral density) therefore the use of two separate wheels. The position and size of the wheel is driven by the size of the filters which are for most of them already available (re-cycling of the ISAAC filters after its de-commissioning). The arrangement of the wheels with one wheel above, and the second one bellow the optical axis is such that it allows an easy change of the filter on the top wheel. The mechanism is mounted on a baseplate, which provides the interface to the cold structure.

Each wheel will be independently motorized. Each motor will have a position sensor that provides the fine initialization signal, the rough initialization signal is provided from a second sensor sensing the position of the wheel. A spur gear with a gear ratio of 1/10 is used to drive the wheel. Since there are 10 filter positions for each wheel, every time the motor makes one turn, the filter wheel will rotate to a new position. This will facilitate the position control of the wheels. Since FIAT is a very sensitive testing device, all covers and openings are light tight. There will be also a labyrinth in the interface to the cold structure close to the optical access. The wheels are mounted on cryogenic adapted ball bearings.

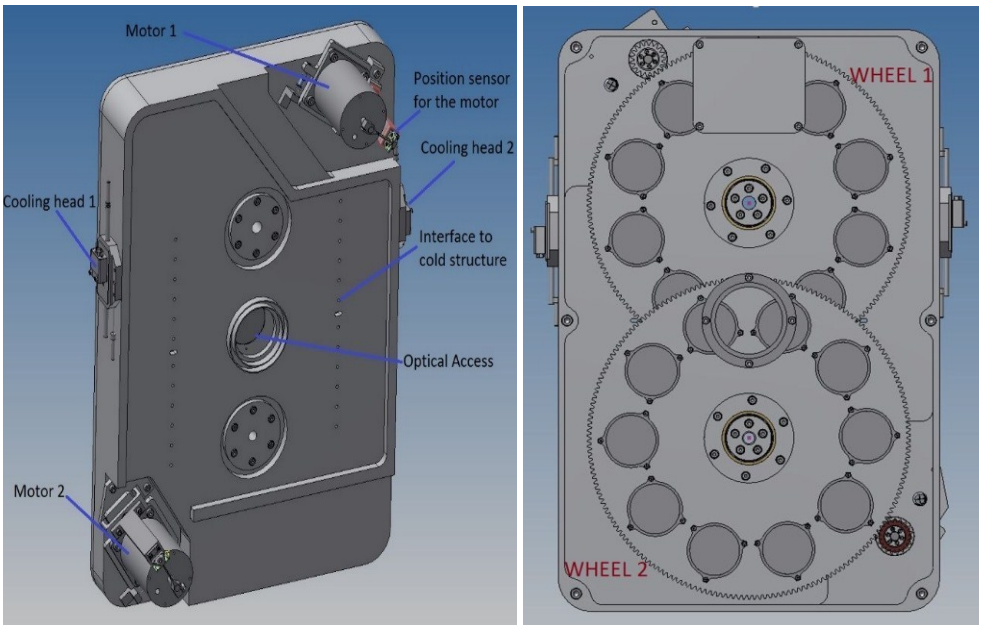

Figure 6. Filter wheel system

5.3 Slide mechanisms

In order to fully meet the requirements two slides were necessary (Fig. 7): The optical and the shutter slides. The optical slide is used to either leave the full aperture beam reaching the detector or to insert the various pre-focal plane optical components in the beam. The second slide is an optical shutter which closes completely and fully light tight the detector in order to assess its dark current limitation. The two slides are built on the same principle. A main guiding bar defines fully the translation direction. This bar is rolling in 2 rolling Ve systems. These Ve's are composed of 2 ball bearings rigidly mounted with rotation axis a 45 degrees angle between the rotation axis. Every guiding Ve is equipped with a third ball bearing which is spring loaded. This elastic rolling element complete the linear guiding system. The two Ve's bearing system are sufficiently separated to each other in order to provide a accurate definition of the translation direction. The secondary guide is only guided with a simple bearing system (one rigidly and one elastically mounted bearing) in order to suppress the last degree of freedom. The slides are driven by Phytron stepper motor of the same type than the one used for the filter wheels. The translation is provided by a small pinion leading a teeth rack. The scanning lens is the only component which requires a very accurate positioning. The optical axis of the lens shall be centred on the main optical axis within a few microns in order to keep the optimal optical quality. The accuracy which can be reached from the stepper motor would not be sufficient. The final positioning of the lens is defined mechanically. The cell containing the lens is free floating in the sliding plane of the slide. While coming in position a reference system which belong to the cold optical assembly will position it accurately centred on the optical axis. The second slide is much simpler, it is only used in order to completely darken the detector. The shutter blade will nevertheless be slightly more elaborated as shown on the preliminary design presented in figure 7. A labyrinth will be implemented in order to guaranty an efficient closing. A flexible connection will link the shutter blade directly to the first stage of the cold head in order to guaranty a sufficiently low temperature.

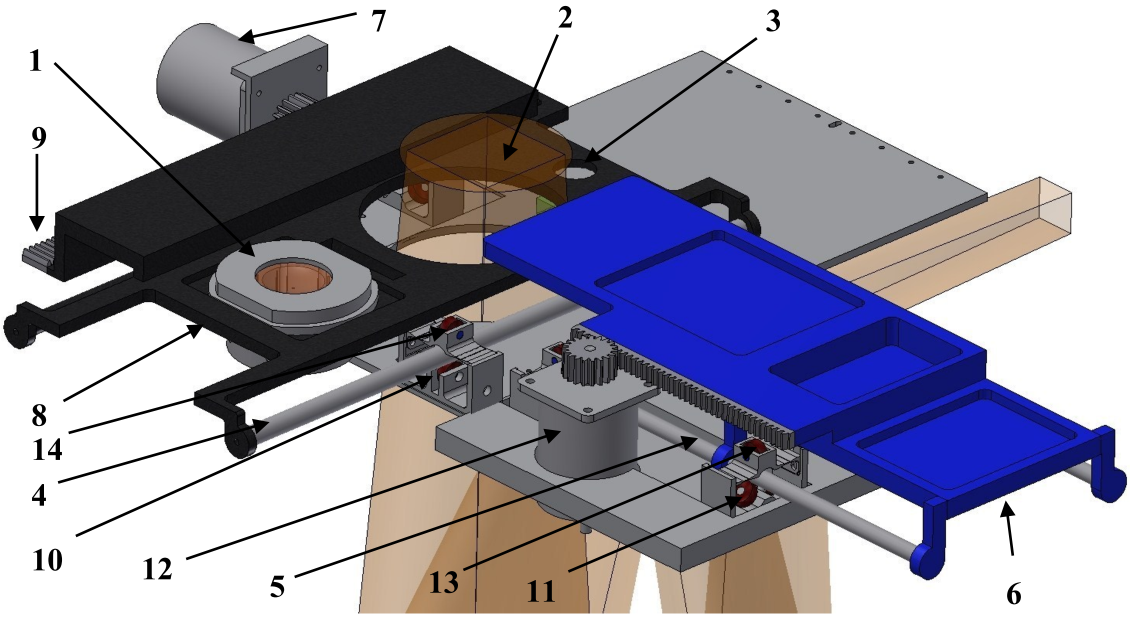

Figure 7. Slide mechanism without light shielding; 1. Scanning lens, 2. Full aperture, 3. Calibration source, 4. Optic slide main guide, 5. Shutter main guiding bar, 6. Shutter slide, 7. Motor of the optic slide, 8. Optic slide, 9. Teeth rack, 10. Secondary guide rigid ball bearing, 11. Rolling Ve rigid ball bearings, 12. Shutter motor, 13. Rolling Ve flexible bearing, 14. Secondary axis flexible bearing. .

5.4 Detector environment

The detector environment is a sort of light tight box (the optical enclosure) in which the various detectors can be installed in their final mount.

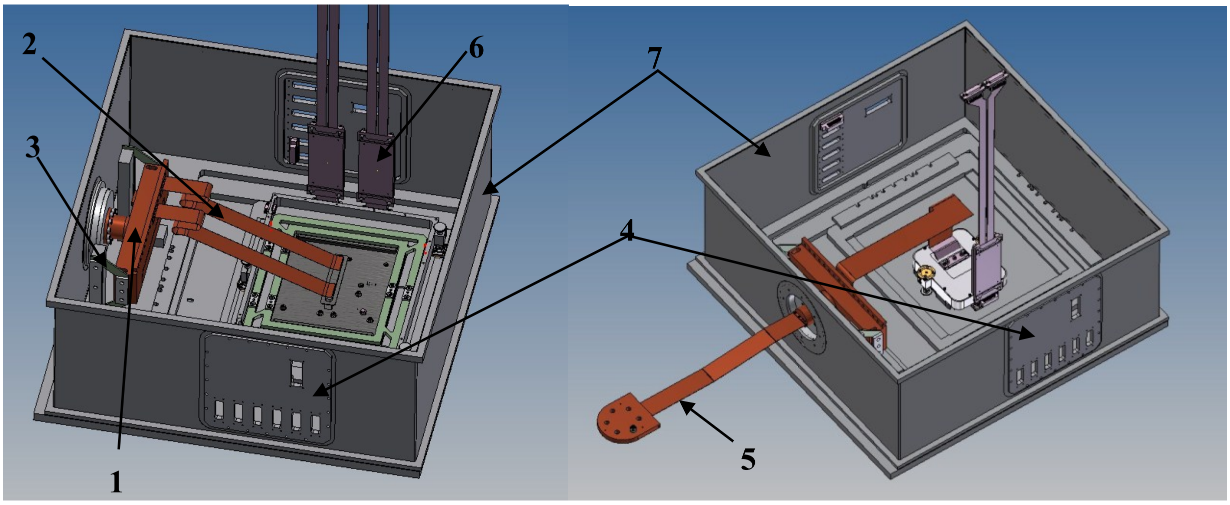

Figure 8. Detector environment with two different detector configurations; 1. Cooling bank, 2. Detector cooling braids, 3. Thermal and electrical insulation structure, 4. Connection interface plates, 5. CCC second stage connection, 6. Detector preamplifiers, 7. Optical enclosure.

The aim being to test indifferently a large number of detectors and detector mosaic, the detectors are installed onto a manual X,Y stage which is set such that the detector under test is on the optical beam. Every detector is mounted using an ESO standard kinematic mount with 3 small Ve blocks. The detector cooling-bank as it was described in the previous section is also shown. This copper bar is supported in such way that it is electrically insulated from the rest of the instrument. The front and back panel of the optical enclosure are fitted with interface plates providing the light tight fed-through for the detector cables.

5.5 Detector to be tested

FIAT should be as versatile as possible but it is actually not possible to imagine all type and size of detector which will have to be tested. This even less if we consider the development speed in the IR detector technology compare to the fact that the facility will be sued for the coming 15 years. Nevertheless a number of already known system has been already planned and designed.

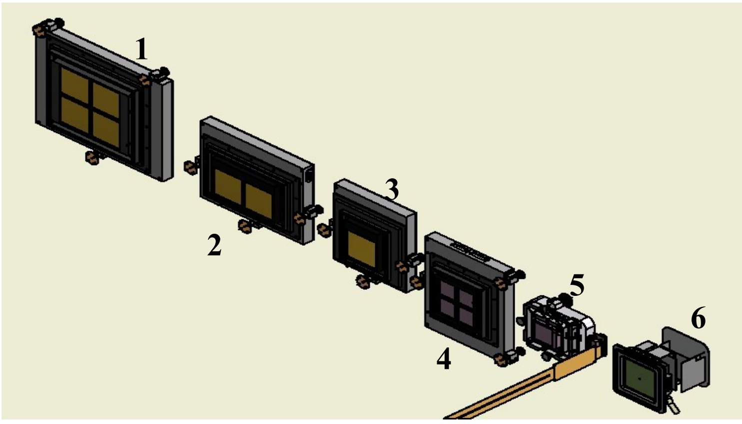

Figure 9. Detector to be tested; 1. 2x2 H4RG with 15µm pixels, 2. 2x1 H4RG with 15µm pixels, 3. 1 H4RG with 15µm pixels, 4. 2x 2H2RG, 5. 1H2RG, 6. 1H4RG with 15µm pixels in the MOONS (next VLT instrument) configuration.

6. GENERAL ARCHITECTURE

In order to complete the facility as an autonomous and compact system the vacuum vessel is installed on a structure built from standard profile. The structure also support the warm optical table which accommodate the warm optical components (optical fiber scanning system, reference black-body…). A lifting device is also integrated in order to allow easy opening of the facility without requiring external crane.

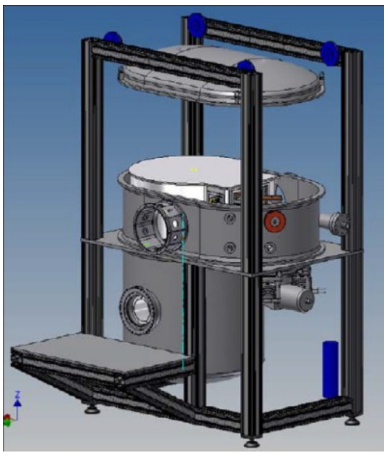

Figure 10. General architecture

7. TRAINING ASPECTS

FIAT has been approved as an ESO internal development project under the condition that it is used to train new designers. A number of specific features have been introduced in the plan in view to fully support the training program. The design is led by a senior engineer. The rather small project has been divided in a number of well identified work-package with very clear definition and interface. The various designers are also parts of the board of the various internal reviews. Regular tutorials are given along the development of the project (Thermal load assessment, mechanism design, ball bearing adaptation and implementation, gearing design, friction study…). The mechanical designers will also take active part in the MAIT but in a swapped configuration. The designer will not integrate and test the sub-system he has designed but the one designed by his colleague. We hope that all of this measures will successfully contribute in an efficient transfer of the experience and knowledge collected over years during the development of a number of large infrared instruments (ISAAC, CRIRES, HAWK-I…) toward a new generation of instrument experts.

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