VERY LARGE TELESCOPE

VLTI Spectro-Imager

VSI Phase A - Mechanics & Cryogenic Design

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<th>Author(s)</th>
<th>L. Jocou</th>
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</table>
Contents

1 Applicable and Reference Documents 4
  1.1 Applicable Documents ................................................. 4
  1.2 Reference Documents ................................................. 4

2 Acronyms 5

3 Scope 6

4 Overview of the mechanical design 6

5 Mechanical design 7
  5.1 Common path .......................................................... 7
    5.1.1 Optical bench .................................................... 8
    5.1.2 Switchyard ...................................................... 8
    5.1.3 Shutters .......................................................... 9
    5.1.4 FT OPD correction ............................................... 9
    5.1.5 Tip-Tilt correction ............................................. 9
    5.1.6 Atmospheric dispersion compensator .......................... 9
    5.1.7 Imaging system ................................................ 10
    5.1.8 Beam splitter device .......................................... 10
  5.2 Scientific instrument ................................................. 10
    5.2.1 Beam injection module ....................................... 10
    5.2.2 Polarization control ......................................... 12
    5.2.3 Beam combiner mount ........................................ 12
    5.2.4 Spectrograph assembly ....................................... 12
  5.3 Calibration-Alignment Tool ......................................... 20
    5.3.1 Beam splitter ................................................... 20
    5.3.2 Beam collimation ............................................. 21
    5.3.3 Beam switch ................................................... 21
    5.3.4 Source box ..................................................... 22
  5.4 Control system ....................................................... 22
  5.5 Extension to 6/8 telescopes ......................................... 22
    5.5.1 Common path ................................................... 22
  5.6 Scientific instrument ................................................. 22
    5.6.1 Beam injection: ............................................... 22
    5.6.2 Beam combiner ................................................ 22
    5.6.3 Polarization control ......................................... 22
    5.6.4 Spectrograph ................................................... 22
    5.6.5 CAT .............................................................. 23
  5.7 Degrees of freedom .................................................. 23
  5.8 Earthquake sensitivity ............................................... 24

6 Conclusion 24
1 Applicable and Reference Documents

1.1 Applicable Documents

<table>
<thead>
<tr>
<th>No.</th>
<th>Document title</th>
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<td>Technical Requirements and Specifications for the Phase A Study of the VSI Instrument</td>
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1.2 Reference Documents

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<td>VLTI Spectro-Imager — Technical Proposal for a second generation VLTI instrument</td>
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2 Acronyms

AMBER  Astronomical Multi-BEam Recombiner
AO     Adaptive Optics
AT     Auxiliary telescopes (1.8m)
FINITO First generation fringe tracking unit
FOV    Field of View
FT     Fringe Tracker
FWHM   Full Width at Half Maximum
IONIC  Integrated Optics Near-Infrared Combiner
IOTA   Infrared Optical Telescope Array
IR     Infra-Red
NIR    Near Infrared
PRIMA  Phase-Reference Imaging and Micro-arcsecond Astrometry
SNR    Signal to Noise Ratio
STS    Star Telescope Separator
TBC    To Be Confirmed
TBD    To Be Defined
TBW    To Be Written
UT     Unit Telescope (8m)
VINCI  VLT Interferometer Near-Infrared Commissioning Instrument
VITRUV Not an acronym. Project for a VLTI second generation instrument
VLT    Very Large Telescope
VLTI   Very Large Telescope Interferometer
VSI    VLTI Spectro-Imager
3 Scope

This document presents the mechanical design of the VSI scientific path. It follows the system study presented in RD3. This one is complying with an operation with four telescopes but most of the sub-systems are studied to manage 6 beams. The mechanical design allows to operate with four telescopes using the VLTI dual feed PRIMA mode capability. A particular attention has been given to several critical sub-assemblies of the system: the beam injection and the spectrograph cryostat.

4 Overview of the mechanical design

The Figure 1 presents a schematic view of the VSI system. It is composed of seven mains assemblies:

1. **Common Path (CP)**: ensures that the VLTI incoming light is properly distributed between the fringe tracker and the scientific instrument.

2. **Fringe Tracker (FT)**: ensures the best possible level of array coherencing/cophasing by monitoring in real time optical path fluctuations.

3. **Scientific Instrument (SI)**: delivers the interferometric observable that will lead to the final image reconstruction. Its function is to record the interferometric signal gathered on scientific targets and calibration sources (both on sky and in lab).

4. **Calibration-Alignment Tools (CAT)**: provides coherent and uncoherent sources to make alignment and internal interferometric calibrations of both the FT and SI during integration or operation phases;

5. **Control system**: computers, softwares and electronics for controled functions such as motors, piezo devices, detectors, sensors and others active systems in VSI;

6. **Observation support software**: software package dedicated to the reduction of the interferometric data aiming to provide up to reconstructed images;

The path of the light in the instrument is the following: The VLTI beams enters the common path of VSI at the bottom left of the Figure 1. The beams are first folded by a switchyard to allow to address the delay line beams on suitable VSI arms. Two others mirrors allow to perform a Tip-Tilt correction and an active OPD correction allowing to stabilize both the flux and the interference fringes. The beams pass then through an ADC correcting the transversal atmospheric dispersion effect and a set of dichroic plates feeding an imaging system which performs the tip-tilt sensing. A second set of dichroic plates allow to distribute the beams between the scientific instrument and the fringe tracker. In the scientific instrument each beam is collected and injected in fiber optics which feeds the beam combiner. The beam combination is achieved by a Integrated Optics Component (IOC) to optimize the stability aspect. The output of the IOC is then imaged on a detector by the way of a grating spectrograph. In the fringe tracker the beams are first combined by a bulk optics system. After combination each pairwise combined beams are collected by a fiber optics that fed a low resolution grating spectrograph.

This document deals with the mechanical aspects of the common path, the scientific instrument, the CAT and the control system. The fringe tracker is not adressed here but is described in RD5.

The reader can refer to RD3 for the functional analysis of the system.
5 Mechanical design

5.1 Common path

In order to manage the dual feed operation with 4 beams in the first development phase of VSI (i.e. 4 reference beams + 4 star beams), the current design of the common path features 8 operating arms. The configuration in dual feed mode is detailed in RD3.
5.1.1 Optical bench

We propose to implement commercial tables fitting the earthquake requirements (AD2). In the current design we propose to use three tables as described Figure 2: one dedicated to the common path, a second one supporting the fringe tracker assembly and the scientific instrument injection and a last one is a structure holding only SI spectrograph. This concept requires only small tables and it allows a better accessibility for integration and maintenance purposes. The last table is placed at lower height to leave the beams free to feed AMBER and FINITO instrument. An enclosure will be implemented on the two first tables to protect the instrument against dust or turbulence.

![Figure 2: Distribution of the main VSI assemblies on the optical bench.](image)

5.1.2 Switchyard

The concept proposed is described Figure 3. Each mirror is holded on a large stroke translation stage moving along U axis. The mirrors could thus take 8 positions to address the beams to the convenient arms of VSI (left part of Figure 3). Another motorized motion translates the set of mirrors along the V axis to escape the mirrors and leave the VLTI beams available for AMBER and FINITO. This last motion could be done by 2 blocks of 4 mirrors or 4 blocks of 2 mirrors. The beam spacing being fixed at 35 mm to comply with the FT requirements (see RD5), a stroke of $8 \times 35 \text{mm}$ is required to performed the addressing of the beams in VSI while a stroke of about 40 mm is necessary to escape the beams for AMBER and FINITO (see RD. These two requirements are complied with standard translation stages available at OWIS$^1$ (see references DTM 80 or LIMES 150).

$^1$http://www.owis-staufen.de/
5.1.3 Shutters

Standard commercial shutters could be used to cut the beams coming either from the VLTI or from the CAT assembly. The position of the shutters will be defined in the next phase.

5.1.4 FT OPD correction

The concept of this sub-assembly is presented in the FT concept (see RD5).

5.1.5 Tip-Tilt correction

This correction is required to optimize the coupling of the VLTI beams in the SI and FT fibers. Standard commercial system available at Physik Instrumente\(^2\) or at Optophase\(^3\) meet the requirements of VSI. The next phase should foresee some tests to validate the system.

5.1.6 Atmospheric dispersion compensator

The design of the ADC mechanics is not defined yet since it is not a critical part. The constraints are relaxed due to the fact that misalignments due to the ADC rotation will be compensated using the tip-tilt correction. The counter rotation between prisms will be performed by two commercial motorized rotation stages. Stage like OWIS DMT40 meet the requirements according to NAOS experience.

5.1.7 Imaging system

This system image the VLTI beams either to perform the tip-tilt sensing or to simplify the the pointing and alignment operations. As described Figure 4 the implemented system will be an adaptation of the IRIS system. Our system could thus use a PICNIC detector with the cryostat

\(^2\)http://www.physikinstrumente.com
\(^3\)http://www.optophase.com/
developed for IRIS. The mechanics of the imaging system will have to be defined in the next phase after design of the exact optical layout. Nevertheless no critical point is noticed.

5.1.8 Beam splitter device

The device will manage the splitting of the light between the Fringe tracker operating in H or K band and the scientific instrument observing in J, H or K band. Two concepts are proposed for this device (Figure 5). The first concept uses only one dichroic to manage the instrumental configuration 1 and 2. The switching between these two configurations is obtained by inserting the mirror M3 in the optical layout. In order to manage the instrumental configuration 3 the M3 could be replaced by a simple beam splitter. This layout allows also to integrate the ADC in a fixed position to work for both FT and SI. The second concept is standard since it uses a wheel holding the 3 required dichroics to fulfill all the instrumental configurations. In this case, the ADC will be placed before the switchyard. These two concepts will be studied during the next phase in term of optical throughput and stability.

5.2 Scientific instrument

The scientific instrument is aimed to perform suitable fringe acquisition in the required spectral band with the specified resolution.

5.2.1 Beam injection module

This module ensures the collection of the VLTI beams and the coupling in the fibers feeding the IO beam combiner. The philosophy for the assembly is to design a module which can be aligned independently of the optical bench (Figure 6). To ensure a very stable module the number of degree of freedom are limited. Most of the adjustments are thus made with shims during integration in Europe. Once a module is integrated the coupling with the VLTI beams is obtained by two angular adjustments of the whole assembly on the main bench (not described in the drawing). The module

Figure 4: Layout of the imaging system
Figure 5: Instrumental configuration and concepts proposed to distribute the light between FT and SI. In concept 1, M3 mirror ensure the selection of the band.

Table 1: Motorized functions in the beam injection.

<table>
<thead>
<tr>
<th>Function</th>
<th>Axis</th>
<th>Stroke/accuracy</th>
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<td>OPD compensation</td>
<td>Z (along optical axis)</td>
<td>10mm/1μm</td>
<td>Physik Instrumente (PI) - M110</td>
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<tr>
<td>Fiber selection</td>
<td>X or Y</td>
<td>2 to 3mm/1μm</td>
<td>PI - M110</td>
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<tr>
<td>Coupling optimisation</td>
<td>X, Y</td>
<td>100μm/10nm</td>
<td>PI Nanocube</td>
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integrates four motorized stages. The functions, specifications and reference of the stages used for the current model are described in the table 1.

Two stacked stages are used to ensure the fine resolution for fiber coupling optimization and fiber selection allowing to select the operating spectral band. These two functions could however be fulfilled by only one stage with the systems proposed by Attocube System or Jena allowing to manage stroke of few millimeter and high precision accuracy. The fiber selection will be done using a translation in the focal plane along the X direction. The whole assembly is placed on a translation stage which performs an OPD compensation due to longitudinal chromatic opd between FT and SI. To achieve a compact monolithic unit a stiff stress-relieved aluminum structure is implemented. This keeps the parts together within the required tolerances and stability.

The overall dimensions are still subject to changes as the final components were not yet decided. The same beam injection module shall be used for the CAT as a collimation module to produce the beams for the interferometric calibration tool.
Figure 6: Beam injection module. In this presented design, fiber selection and flux optimisation are performed using two different stages.

5.2.2 Polarization control

The polarization control for the 4T beam combiner is obtained by an optical device. No mechanics is thus required.

5.2.3 Beam combiner mount

The mechanics of the beam combiner sub-system mainly concerns the holders of the IO chips. Due to thermal emission issue, we have demonstrated in RD7 that beam combiner has to be cooled down at 233K ±5K. The IO beam combiners are thus integrated inside the spectrograph dewar. The IO chip mechanical holder has noth to ensure a proper interface with the spectrograph mechanics and to guarantee a stable maintaining of the IO chip as it is the optical slit of the spectrograph. This device is composed by a rigid support mounted on the spectrograph cold bench which holds the IO chips both for 4 or 6 telescope operations. This part is installed on the spectrograph bench to optimize the stability. The suggested solution consists in a rigid support attached to the optical bench that can be made of stainless steel + fiberglass to establish a "weak" thermal link to the IO devices. If required the temperature could be controlled by a heater stage in close loop. In the next phase a prototype of this mechanical part and the interfacing with spectrograph will be done to validate the cooling process of the IO chip and the stability of the assembly.

5.2.4 Spectrograph assembly

The presented mechanical design is based on a former optical design that is not any more valid. We choose at the beginning of this mechanical analysis to avoid to wait for an optical design that take into account all the constraints of the VSI system, including all the considerations related to
the integrated optics beam combiner, but meet most of the major usual constraints for the design of a spectrograph. It means that both optical and mechanical design will be reconsidered during the next phase to take into account all relevant constraints.

As it is shown Figure 7 the optical design is based on three different optical trains (each optimized for a single spectral band - JHK). Each train is composed by one IO chip, a slit mask, a collimator and a filter. Moreover there are four different selectable spectral resolutions obtained with dispersive devices mounted on the same rotating turret.

![Figure 7: Concept of the spectrograph. Three IO beam combiner+collimator has to be implemented to cover the whole spectral band.](image)

**Cryo-mechanics**

*Mechanical design*

The VSI optics layout, described hereafter is mounted on an aluminum optical bench that is also the back-plate of the nitrogen vessel of the cryostat for having a uniform cooling of the opticalcomponents. A 3D design of all the components has been realized and the overall mechanical layout is depicted in Figure 8. The positions of the motorized axes have been optimized to have both the internal axes and the external motors in the most convenient arrangement.

The main mechanical components of the VSI spectrograph that will be individually discussed in the following are:

- Three supports of IO with cold slit and dark screen
- Three fixed collimators mounts
- One linear stage for band selection
- One linear stage for flat fielding
- One rotating stage housing the dispersing devices
- One fixed camera mount
The array stage and its movements

**Integrated Optics assembly**

As described previously, the IO chips for both 4 and 6 telescope operation are mounted on the spectrograph cold bench. The IO support should be installed on the same optical bench of the spectrograph and a temperature control is needed for safety reasons to avoid the IO components are cooled down to destructive temperatures. Other solutions, previously analyzed and based on Peltier cells applied to the external wall of the cryostat by means of an O-ring seems not to be viable. The components chosen to hold the IO chips have to be finely tuned to find the best compromise between a suitable cooling rate of the IO and the extra consumption of LN$_2$ due to the heaters themselves. Also in this case the construction of a prototype is mandatory. In order to shield the 233K region, a fixed cold mask will be mounted as near as possible to the IO edges, in between the IO itself and the dark plate. Furthermore a cold screen is required very close to the IO to get a dark image of the whole optical system. The suggested solution consists in a small cold blade driven by a vertical linear stage composed by a threaded cursor and a leading gear moved by cryogenic motor. The range of this device is assumed to be of the order of 10mm and a low accuracy is required.

**Collimators mounts**

The individual lenses constituting the collimators are fixed and can be integrated and mechanically aligned in a single aluminium mount rigidly connected with the optical bench. We foresee to mount the lenses using common techniques based on springs or elastic rings to allow for different expansion coefficients between the used glasses and the aluminum support.

**Band selection**

The selection of the spectral channel is provided by moving a 45° flat mirror located on one side of the three collimators and installed on a linear stage. Since the working range of this mirror is of the order of 300mm and the positioning accuracy is 0.5mm we suggest a linear stage conceptually
similar to the one adopted for the IO dark: the mirror is mounted on a threated flange driven by a leading gear operated by a warm motor. The moving plate is thermally connected with the optical bench by means of copper straps to cool down as much as possible the mirror downward 77K.

**Flat field device**

This device is based on a linear stage that downloads (upon request), at the pupil plane, a screen illuminated by the dedicated fiber. The movement range is of the order of 100m and the required accuracy is largely achieved by a custom solution as for the channel selection unit, by envisaging a warm motor.

**Grating turret**

Such unit is a rotating plate supporting all the three gratings at medium, intermediate and high resolution along with the low resolution device (LR). To achieve the positioning repeatability of 5 pixels (i.e. 37 arcsec with the current camera) and the required stability of 1/5 of SRE, i.e. 0.4 pixels (about 3 arcsec), we envisage a device based on two large worm wheel gears preloaded by springs to strongly reduce the backlash and driven by a warm motor. In Figure 9 the 2D design of the turret with all the dispersive devices on its top is given. The gratings are rigidly mounted on the turret and properly oriented to match the required angle between the beam coming from the collimator and the one going toward the camera. In particular, to get the full spectra on the array with the high resolution ($R \sim 12000$) grating (HR), a scanning sequence of $4(J)+2(H)+4(K)=10$ positions is required (see RD4). In Figure 9 is shown that by rotating that grating of an angle $= 14^\circ$ around the turret axis, we are able to cover the entire range; the two limiting positions are indicated in red and blue, respectively. The same rotation also allows for a fine tuning needed to center onto the array the H and K bands in the intermediate resolution ($R \sim 5000$) mode.

In other words a rotation around the central axis of the turret, driven by a warm motor, allows also for both an adequate scanning motion and for conveniently centering the dispersed bands, thus saving two additional cryogenic motors.

The LR device aims to provide variable dispersion (requirement of the function is to be confirmed). It is composed by two counter-rotating prisms (or gratings) driven by a cryo-motor and a system of three bevel gears. The maximum rotation angle is $90^\circ$ ($180^\circ$ difference) and the required precision in about 1°. As the other movable devices, also the gratings and prisms are thermally connected to the cold bench with copper straps. As an alternative to the custom solution based on worm wheels gears, a XYZ cryogenic stage can be evaluated in the next phase. The features of this device seems to fulfill our requirements and this solution based on the same cryo-motors (Pytron) can be explored in deeper detail aiming to avoid the construction of an ad hoc prototype.

**Camera mount**

For this mount we can reckon with the same issue described in the collimator mounts.

**Cryogenic system**

The Cryostat of VSI can be imagined as a box like structure with a foot print of about $1 \times 1 \times 0.4$m but with an irregular shape due to the folded optical path. The temperature of the whole mount must be not higher than the temperature of the detector assembly to avoid dust deposition. The optical bench that has to be cooled down is actually one side of a nitrogen vessel ensuring a good thermal contact with the cryogenic liquid. The whole optical bench is enclosed in a radiation shield that is in tight contact with the cold bench itself.
Figure 9: 2D sketch of the rotating turret

Since the cryostat is composed of several flat welded surfaces mainly stressed by the pressure load, a detailed analysis of the mechanical solution can be performed only after an accurate FEA calculation needed to properly model both the shape and the size of reinforcing ribs needed to keep the flexures within the tolerances. Special care has also to be devoted to FEA analysis needed to model the optical bench under gravity, pressure and thermal loads.

Concerning the pumping process, since the estimated free room inside the cryostat should be comparable with that of AMBER, we can adopt the same evacuation system already in operation, with pressure gauges and temperature controls compatible with ESO requirements (See VLT-TRE-ESO-15800-2315).

The Cryostat will be equipped with 3 types of vacuum connectors/feedthroughs:

- Electrical connectors
- Mechanical feed-through
- Optical fiber feed-through

The first two are widely used, while the third one is a custom application whose development deserves the realization of a prototype during the next phase.

Consumption of cooling agents

From a rough calculation we can estimate an inner radiating surface (vessel + cold shield) of about 17000 cm$^2$; by assuming conservative emissivity values of 0.15 for the 300K surface and 0.12 for the cold one, we can estimate a radiative input of about 60W. Then a holding time of 24 hours can be achieved with a consumption of 36 liters of LN$\text{$_2$}$. The vessel has an height of about 20cm, therefore the available volume is around 50 liters providing a good margin for a holding time of one day even without the use of any mylar insulation layers.
Cryogenic alarms and safety

VSI will comply with the ESO safety requirement. In particular, it will be equipped with acoustic alarm in case there is an error condition. Moreover, VSI will be interfaced with the Paranal Central Alarm System as well to immediately communicate any warning which requires a prompt reaction. Internal temperatures of the cryostat have to be continuously monitored to preserve the safety of hardware and personnel. Also the gas output from the vessel in which nitrogen is located has to be monitored providing an alarm when the venting is lacking. The quite standard nature of our cryostat does not require sophisticated alarm systems. The only component to be controlled with a particular care is the heater of the IO inside the cryostat (see Sect. 5.10), for which a passive thermal interrupt is envisaged since the component cannot be cooled down at a lower temperature that 210K.

Motors and controls

The following motors are required:

- 3 cryo-motors for selecting slit or dark in front of each IO
- 1 room temperature motor for positioning the flat mirror
- 1 room temperature motor for the grating turret (usable for HR scanning, as well)
- 1 room temperature motor for inserting the screen for flat-fielding
- 1 cryogenic motor for the counteracting prisms dedicated to low resolution mode
- 1 room temperature motor for positioning a dark screen in front of the IR array

This means a total of 4 motors at room temperature and 4 cryo-motors. In Table 2 the functions to be motorized are summarized along with the indication of relevant parameters, such as needed travel, number of positions and mechanical resolution. Two types of motors and relative controls used by ESO are under evaluation: the 5-phase Bergher-Lahr motor (used in AMBER) that can be modified to be available as cryogenics, or the more expensive and larger 2-phase cryo-motors from Phytron. A choice between this two models will be done upon the type of use (warm or cold), space, resolution and needed torque.

For *warm* movements i.e. by using an external motor at room temperature, we suggest the first type that is cheaper and is widely used by ESO. For movements that require cryo-motors, the second choice (and more expensive, one axis costs about 2000 Euros) is preferable, since there are cryo version certified for High Vacuum ($10^{-7}$ mbar) and low temperature environments. At least one movement needs to be operated by a cryo-motor. It is the mechanics of the LR mode mounted on the turret stage. For this application a small cryo-motor is envisaged such as the Phytron VSS-UHVC19 or VSS-UHVC25 with a diameter of 19 or 25mm. Typical drive torque values of these motors are ranging between 2.5 and 9 mNm that can be increased by a factor of 50-100 if coupled with a proper gear provided by Phytron (VGPL22). It should be noticed that having the motors in a warm environment requires a greater care in the design of the cryo-mech coupling. In case of external motors three different kind of insulation have to be envisaged for any axis: a vacuum connection, a cardan coupling and a fiberglass segment for thermal insulation.

Depending on the final specifications stemming from the optical design, and if a thermal cycle is expected to be not critical for the re-alignment of the spectrograph so that we can foresee 2-3 days
of downtime between 2 cooling cycles, then we can take into account the possibility to have all the movements driven by Phytron cryo motors (several types are currently available) that should have a much lower failure percentage respect to the BL motors adapted for low working temperatures.

### Table 2: Overview of the moving functions.

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<th>Type</th>
<th>Travel</th>
<th>Positions</th>
<th>Resolution</th>
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<td>linear</td>
<td>10mm</td>
<td>3</td>
<td>0.5mm</td>
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<td>Flat mirror</td>
<td>1</td>
<td>linear</td>
<td>300mm</td>
<td>3</td>
<td>0.5mm</td>
</tr>
<tr>
<td>Grating turret</td>
<td>1</td>
<td>rotating</td>
<td>±180°</td>
<td>cont.</td>
<td>~ 30arcsec</td>
</tr>
<tr>
<td>Counteracting prisms - cryo.</td>
<td>1 a</td>
<td>linear</td>
<td>±90°</td>
<td>cont.</td>
<td>1°</td>
</tr>
<tr>
<td>Illuminated flat</td>
<td>1</td>
<td>linear</td>
<td>50mm</td>
<td>2</td>
<td>0.5-1mm</td>
</tr>
<tr>
<td>Detector dark</td>
<td>1</td>
<td>linear</td>
<td>40mm</td>
<td>2</td>
<td>0.5-1mm</td>
</tr>
</tbody>
</table>

### Power dissipation

The power dissipation of the cryo-motors is, nominally, very small (see Figure 10 for the smallest motors). In practice, the local temperature increase generated by a cryo-motor varies depending on the specific mechanical application i.e. the needed torque, thermal contact to the optical bench, duration of the pulse. For this reason and also to avoid electrical interference, a design of the mechanical systems allows the powering-off of the cryo-motors after the motion.

![Figure 10: Nominal power dissipation of the Phytron motors.](image)

### Detector General concept

VSI community has discussed whether or not the double-dewar design, a concept originally adopted for AMBER (one for the spectrograph opto-mechanics and one for the IR array), could still represent a useful alternative to the more common single-dewar solution. This latter presents few but substantial advantages in term of:

- **optical design** no optical extension is required; a lesser number of optical elements is needed; the camera lens may be located near the detector
• optical alignment
• mechanical stability and compactness
• management a lesser amount of interface details have to be agreed
• baffling and shielding the array from stray-light
• reduction of costs

Moreover, following this approach, the number of thermal cycles (that could affect the increasing number of bad pixels) will be significantly reduced and the detector can remain in a uncontaminated environment until the final integration.

*Single dewar mechanical solution*

The single-dewar design could be split in two alternative solutions:

A - the IR-array is inserted in the dewar of the spectrograph that is mechanically developed and cabled in order to accept it. This solution offers the advantage to carefully test the thermal link of the array in its final location, but a separate (may be commercial) cryostat has to be set up for testing the array prior to the final assembly.

B - the electro-mechanics components needed for controlling and moving the array are developed separately from the spectrograph and only the mechanical interface between the spectrograph team and the IR array team has to be defined. This interface can simply be a flange, compatible with both the spectrograph and the dewar used for testing the array, that holds all cabilities, boards, vacuum connectors and mechanics needed to the array. It can be freely developed and tested by the array team and can be attached to one side of the cryostat just for a final integration. Care must be put for studying an adequate thermal link to the array. The cryo mech design of the spectrograph has just to take into account: (i) the room needed for the detector (along with its cryo-mech), (ii) the diameter of the hole where the flange has to be accomodated, (iii) the position of its fixing bolts.

*Mechanical interface*

We have comparatively evaluating and finally we decided for the A alternative which presents the additional advantage to state a clearer interface between the two consortium partners in charge to provide the spectrograph and the detector. In the following the relevant aspects of this interface are presented:

- The preliminary operations of alignment will be done at room temperature by using an optical CCD as a detector and by taking into account the adequate ray tracing for the provisional detector and ambient temperature. Therefore the spectrograph does not need the IR array since the preliminary lab operations, but only during the final integration

- The optical tolerances are given in Table 3: the positioning tolerances for the array are referred to a RMS decrease of the spot diagram of 10%.
Table 3: Optical tolerances relevant for the detector mounting.

<table>
<thead>
<tr>
<th>Movement</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>tilt (on x and y)</td>
<td>0.3°</td>
</tr>
<tr>
<td>tilt around optical axis (z)</td>
<td>30 arcsecond</td>
</tr>
<tr>
<td>piston</td>
<td>+ 0.1 mm ; - 0.3 mm</td>
</tr>
</tbody>
</table>

The exact working temperature of the array will be determined after the first laboratory tests. The de-focusing due to a temperature difference is 0.15 mm/degree, therefore we have to determine such working temperature with an accuracy between +0.7 and -2.0 degrees. This temperature must not be lower than the temperature of the overall spectrograph to avoid dust deposition. Provided these tolerance values, mounting of the detector appears quite straightforward:

- The required tolerances are quite large and then can be satisfied just with the a precision machining, provided a careful thermal study has been done. The d -centering can be easily measured and then adjusted with the camera opened and warm. Therefore, no movable mounting seems to be needed, but only a fixed position for the array. It is worthwhile to consider a warm movement to allow adjustment for de-centering and, possibly, de-focusing. In Figure 11 a concept of the array mount with warm X-Y movements is depicted: the translation stages are oversized to allow a better view of their mechanics. The X-Y stages have blazed sides in order to ensure a better contact and stability in every position: a detail is shown in Figure 12.

- The spectrograph will provide the thermal and mechanical link for mounting the array that should be provided with the fan-out boards, any additional cold electronics and enclosure. In other word the exact definition of the interface will consist in defining the details of this link.

- The spectrograph cryo-mechanical layout envisages a two position mechanical switch to load down a cold and dark screen in the optical beam just in front of the array for evaluating, upon request, its intrinsic performance.

5.3 Calibration-Alignment Tool

This device will produce 8 coherent channels to feed the 4 arms of the FT and SI beam combiners for calibration and alignment purposes.

5.3.1 Beam splitter

The beam splitting is ensured by a IO chip coupled to a set of single mode fibers. The mechanics of this sub-system has only to hold the three IO chips required. Its design will be defined in the next phase.
5.3.2 Beam collimation

This system collect the light coming from the IO beam splitter to produce a collimated beam similar to the VLTI. The beam injection module presented section 5.2 will be adapted to comply with the mechanical implemtation required for the CAT. The motorized stage ensuring the OPD compensation will be replaced by a piezo actuation to make a scan of the fringes for the interferometric calibration.

5.3.3 Beam switch

This sub-assembly is not defined yet. According to the beam spacing this function could done with a single 30×300 mm mirror cutting the VLTI beams and folding the 8 CAT beams to feed FT and SI. This function will be ensured by a standard rotation or translation stage according to the space available on the bench. The motor will be chosen to guarantee an angular repositioning of few arcsecond and then maintain the fiber coupling.
5.3.4 Source box

This box contains required sources (Halogen lamps, lasers) and the optics required to inject the flux in the fiber of the beam splitting device. The global implementation of this box has to be defined. Two motorized wheel or drawer will be implemented to manage the selection of the Fabry-Perot etalons and the density filter set. This box will use standard motors and sensors. No critical elements have been identified in this sub-system.

5.4 Control system

This concerns the management of the cables on the optical tables. Specifics path will be managed to ensure an easy access and a stiff clamping of the cables on the tables. The global implementation will consider this aspect in the next phase.

5.5 Extension to 6/8 telescopes

5.5.1 Common path

No extension is required for the Common path since 8 arms will be implemented from the beginning to manage the dual feed operation.

5.6 Scientific instrument

5.6.1 Beam injection:

Like the common path 8 beams injection modules will be integrated from the beginning.

5.6.2 Beam combiner

The operation with 6 or 8 beams will require a dedicated component (see RD4). The extension thus mainly concerns the integration of these components in the spectrograph environment.

5.6.3 Polarization control

The optical configuration of the 6 beam combiner do not allow to control the polarization as it is done with the 4 beam combiner. In 6 or 8 beam operation, we propose to use a mechanical fiber polarization controller (also called Lefebvre loops). This one forces the birefringence by twisting the fiber to optimize the instrumental contrast. One device per injection fiber will be implemented. This device will be motorized to avoid any manual intervention. The concept and the mechanical device will be more deeply investigated during the further phase.

5.6.4 Spectrograph

The spectrograph will have to present available slot to implement the additional IO 6/8 beam combiners and the feedthrough to allow the passage of the fiber through the dewar. The mechanics used for the 4 beam combiner should be usable for the 6/8 beam combiner.
5.6.5 CAT

The CAT is foreseen to provide 8 beams to allow calibration process in dual feed operation.

5.7 Degrees of freedom

The table 4 presents a preliminary listing of the required the degrees of freedom or motorized functions of VSI (not including the fringe tracker). The distribution of the degrees of freedom in the system will be more deeply studied in the next phase. In the baseline, the CAT is first aligned with the VLTI. Once this alignment done; the CAT is used as a reference for the alignment of fringe tracker and scientific instrument. These assemblies have thus to present the DOF required to allow this alignment.

<table>
<thead>
<tr>
<th>Common Path</th>
<th>Manuel DOF</th>
<th>Function</th>
<th>Motorized DOF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switchyard</td>
<td>shims</td>
<td>Pre-positioning</td>
<td>8 + 4)</td>
</tr>
<tr>
<td>OPD correction</td>
<td>shims</td>
<td>Pre-positioning</td>
<td>8</td>
</tr>
<tr>
<td>Tip-tilt system</td>
<td>8 × 4</td>
<td>alignment</td>
<td>8 × 2</td>
</tr>
<tr>
<td>Imaging system</td>
<td>8 × 4</td>
<td>alignment</td>
<td></td>
</tr>
<tr>
<td>ADC</td>
<td>shims</td>
<td>Pre-positioning</td>
<td>8 × 2</td>
</tr>
<tr>
<td>Beam splitter device</td>
<td>shims</td>
<td>Pre-positioning</td>
<td>8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scientific instrument</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam injection</td>
<td>2 × 8</td>
<td>alignment</td>
<td>5 × 8</td>
</tr>
<tr>
<td>Polarization control</td>
<td></td>
<td></td>
<td>4 × 2</td>
</tr>
<tr>
<td>Beam combiner</td>
<td>3 times 2 (TBC)*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spectrograph</td>
<td>TBC *</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Detector</td>
<td>3 (TBC)*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Calibration-Alignment Tool</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam splitter</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam injection</td>
<td>2 × 8</td>
<td>alignment</td>
<td>2 × 8</td>
</tr>
<tr>
<td>Beam switching</td>
<td>8 × 4</td>
<td>alignment</td>
<td>2</td>
</tr>
<tr>
<td>Source box</td>
<td>4</td>
<td>alignment</td>
<td>2 3</td>
</tr>
</tbody>
</table>

*: these degrees of freedom will be defined according the dof required in the spectrograph.
5.8 Earthquake sensitivity

The optical tables will be chosen to comply with the earthquake requirements. No other critical points have been identified in the system yet. During the next phase, finite element analysis will be done if critical points are identified.

6 Conclusion

The mechanical design proposed allow to comply with the specifications required in the system design and high level specifications (RD3, ??). No show stoppers have been identified in this phase. The table 5 summarizes the studies i.e. analysis or prototypes which have to be considered in the next phase to optimize th concept.

Table 5: Further study or prototypes to consider in the next phase.

<table>
<thead>
<tr>
<th>Assembly</th>
<th>Sub-system</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Common Path</strong></td>
<td>Beam splitter device</td>
<td>- Mechanical implementation and efficiency trade off</td>
</tr>
<tr>
<td></td>
<td>Iris duplication</td>
<td>- Validation of the solution</td>
</tr>
<tr>
<td></td>
<td>Tip-tilt system</td>
<td>- Selection of the tip-tilt and characterization</td>
</tr>
<tr>
<td><strong>Scientific instrument</strong></td>
<td>Beam injection</td>
<td>- Prototype to validate the concept</td>
</tr>
<tr>
<td></td>
<td>Spectrograph</td>
<td>- Interfacing of the IO component</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Fiber feed-through</td>
</tr>
</tbody>
</table>