Visible & Infrared Survey Telescope for Astronomy

Project Office

Tel: +44 (0)131 668 8411
Fax: +44 (0)131 668 8412
Email: vista@roe.ac.uk,
http://www.roe.ac.uk/atc/projects/vista/

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Document Prepared By:	**Kim Ward IR Camera WPM**	**Signature and Date:**	Kim Ward 2003.11.21 09:10:10 Z
Document Approved By:	**Simon Craig Systems Engineer**	**Signature and Date:**	Simon Craig; Andy Born
Document Released By:	**Alistair McPherson Project Manager**	**Signature and Date:**	Alistair McPherson 2003.11.20 16:13:40 Z

Reviewed By:	**Will Sutherland Project Scientist**	**Signature and Date:**	Will Sutherland 2003.11.20 16:43:52 Z

Change Record

Issue	Date	Section(s) Affected	Description of Change/Change Request Reference/Remarks
1.0	28/10/02	All	New Document
1.1	05/11/03	Marked	Updates commensurate with CREs from camera team [GBD]: VIS-CRE-RAL-06000-0008 (humidity) VIS-CRE-RAL-06000-0012 (non-sidereal tracking) VIS-CRE-RAL-06000-0013 (Services ICD as AD) VIS-CRE-RAL-06000-0014 (WFS accuracy specification) VIS-CRE-RAL-06000-0015 (Filter holder scattered light) VIS-CRE-RAL-06000-0016 (Cass Rotator Temperature)
1.2	07/11/03	Marked up	Updates to get rid of TBRs etc [GBD & AKW]
2.0	20/11/03	Marked	Final changes following review of the CREs by VPO (GBD)

Table of Contents

1 INTRODUCTION

1.1 Scope

This document contains the requirements for the supply of the VISTA IR Camera by the Consortium to the VPO.

1.2 Abbreviations and Acronyms

ADxx	Applicable Document No xx
ATM	Asynchronous Transfer Mode
BOB	Broker for Observation Blocks
CCD	Charge Coupled Device
CIQ	Camera Image Quality
DCS	Detector Control System
Dec	Declination
DFS	Data Flow System
DRDxx	Document Requirement Definition No xx
EED	Encircled Energy Diameter
EMC	Electro-Magnetic Compatibility
ESD	Electro-Static Discharge
ESO	European Southern Observatory
ETC	Exposure Time Calculator
FDR	Final Design Review
FIERA	Fast Imager Electronic Readout Assembly
FITS	Flexible Image Transfer System
FOV	Field Of View
FWHM	Full Width at Half Maximum
HOWFS	High Order Wavefront Sensor
ICD	Interface Control Document
ICS	Instrument Control Software
IQ	Image Quality
IR	Infrared
IRACE	Infrared Array Control Electronics
ITT	Invitation to tender
LCU	Local Control Unit
LEMP	Lightning and Electro Magnetic Pulse
LOWFS	Low Order Wavefront Sensor
LN_2	Liquid Nitrogen
LRU	Line Replaceable unit
M1	Primary Mirror

M2	Secondary Mirror
MLE	Maximum Likely Earthquake
MLI	Multi-layer insulation
MTBF	Mean Time Between Failures
NDR	Non-Destructive Readout
OB	Observation Block
OBE	Operating basis Earthquake
OS	Observation Software
PA	Position Angle
P2PP	Phase 2 Proposal Preparation
PDR	Preliminary Design Review
PE	Protective Earth
RA	Right Ascension
RAL	Rutherford Appleton Laboratory
RDxx	Reference Document No xx
TBC	To be Confirmed.
TBD	To be Determined
TCCD	Technical CCD (Controller)
TCS	Telescope Control System
THD	Total harmonic distortion
TN-S	a particular system earthing configuration
UKATC	United Kingdom Astronomy Technology Centre
UoD	University of Durham Astronomical Instrumentation Group
UT	Universal Time
VISTA	Visible and Infrared Survey Telescope for Astronomy
VLT	Very Large Telescope
VPO	VISTA Project Office
VST	VLT Survey Telescope
VTS	VISTA Technical Specification
WFS	Wave Front Sensor
ZD	Zenith Distance (90° – altitude)

1.3 Definitions

Consortium	The collective term used in this Specification to represent the IR Camera Consortium (RAL, UKATC and UoD).
Tolerances	Where numerical values of deviations are given, unless they are qualified (e.g. by rms), they are to be taken as maximum absolute values.

1.4 Definition of Requirements Under Development

At present, the exact parameters defining harmonic spectrum that may be transmitted to the IR Camera by the VISTA telescope have not yet been determined by the telescope workpackage, and so the values appropriate to the VLT have been adopted as these are assumed to be conservative values for the VISTA case. These parameters which are still provisional are labelled with TBC, defined as follows:

TBC — To be confirmed: a requirement that is correct with the current design information. To be confirmed by the VPO at an agreed date as specified in the relevant section of this document.

1.5 Applicable Documents

The following documents of the exact issue shown form a part of this Technical Specification to the extent specified herein. In the event of conflict between the documents referenced and the content of the present specification, the content of the present specification shall be considered as a superseding requirement.

1.5.1 VPO Documents

[AD01] *IR Detector Technical Specification*, VIS-SPE-ATC-06020-0003-Issue 3, 13 June 2002.

[AD02] *VISTA IR Detector Controller Technical Specification*, VIS-SPE-ATC-06020-0005, Issue 1.0, 6 March 2002.

[AD03] *IR Camera Focal plane Layout Options*, VIS-REP-RAL-06031-0001, Issue 1.0, 12 September 2002

[AD04] *Statement of Work for the VISTA IR Camera,* VIS-SOW-ATC-06000-0007, Issue 1.0, 11 November 2003

1.5.2 ESO Documents

[AD05] *Basic Telescope Definitions*, VLT-SPE-ESO-10000-0016 issue 2, 7 October 1992

[AD06] *VLT Environmental Specification*, VLT-SPE-ESO-10000-0004 Iissue 6, 12 November 1997

[AD07] *Instructions to perform Earthquake analyses for VLT instruments and similar equipment* , VLT-SPE-ESO-10000-1853, Issue 1, 9 December 1999

[AD08] *Service Connection Point Technical Specification*, VLT-SPE-ES0-10000-0013 Issue 4, 16 February 1997

[AD09] *EMC and Power Quality Specification - Part 1*, VLT-SPE-ESO-10000-0002, Issue 2, 11 March 1992

[AD10] *EMC and Power Quality Specification - Part 2*, VLT-SPE-ESO-10000-0003, Issue 1, 05 February 1992

[AD11] *VLT Electronic Design Specification*, VLT-SPE-ESO-10000-0015, Issue 5, 06 March 2001

[AD12] *Acceptance Procedure Electrical Safety and EMC*, VLT-VER-ESO-10000-0958, Issue 2, 1 March 1996

[AD13] *VLT Requirements for Safety Analyses*, VLT-TRE-ESO-00000-0467, Issue 1, 27 July 1993

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[AD19] *VLT Programming Standards*, VLT-PRO-ESO-10000-0228, Issue 1, 10 March 1993

[AD20] *LCU Common Software User Manual*, VLT-MAN-SBI-17210-0001, Issue 3.6, 1 March 2001

[AD21] *VLT Instrumentation Software Specification*, VLT-SPE-ESO-17212-0001 issue 2, 12 April 1995

[AD22] *CCS-LCU Motor Control Module User Manual*, VLT-MAN-ESO-17210-0600, Issue 1.7, 2 October 1998.

[AD23] *Data Interface Control Document*, GEN-SPE-ESO-19400-0794, Issue1.1, 25 November 1997.

[AD24] *Base Instrument Control System User Manual*, VLT-MAN-ESO-17240-0934, Issue 2.3.

[AD25] *Base Observation Software Stub User Manual*, VLT-MAN-ESO-17240-2265, Issue 1.1.

[AD26] *Template Instrument User Manual*, VLT-MAN-ESO-17240-1973, Issue 2.0.

[AD27] *IRACE Detector Control Software User Manual*, VLT-MAN-ESO-14100-1878, Issue 1.3, 2 February 2001

[AD28] *FIERA CCD Controller User Manual*, VLT-MAN-ESO-13640-1388, Issue 1.3 17 February 2001

[AD29] blank

[AD30] *Guidelines for the Development of VLT Application Software*, VLT-MAN-ESO-17210-0667, Issue 1.2, 8 October 2001.

[AD31] *TCS User Manual*, VLT-MAN-ESO-17230-0942, Issue 2.0, 22 March 2002.

[AD32] *Data Flow for VLT Instruments Requirement Specification*, VLT-SPE-ESO-19000-1618, Issue 1.00, 21 April 1999.

1.5.3 Interface Control Documents

[AD33] *Infrared Camera to VISTA Telescope Control System Interface Control Document*, VIS-ICD-ATC-06000-13010, to be released

[AD34] *Interface Control Document between the VLT Control Software and the Observation Handling System*, VLT-ICD-ESO-17240-19200, Issue 1.2, 17 May 1999.

[AD35] *Interface Control Document between the VLT Control Software and the Archive*, VLT-ICD-ESO-17240-19400, Issue 2.6, 17 November 1997.

[AD36] *Telescope Optical Interface to the IR Camera*, VIS-ICD-ATC-01000-06000, Issue 1.0, 16 October 2002

[AD37] *Interface Control Document between the Instrument Mount to Cameras*, VIS-ICD-ATC-04000-06000, Issue 2.0, 16 Oct 2002.

[AD38] *LCU Location and Cable Wrap Schedules*, VIS-SPE-ATC-01000-0011, Issue A. (to be revised with cable wrap SCP locations)

[AD39] removed - same as AD61

[AD40] *Telescope to IR Camera Services ICD,* VIS-ICD-ATC-01000-04020, Issue 1.0, 20 November 2002. (To be revised)

[AD41] *ICD for Power and Services between Enclosure Buildings WP and All Users*, VIS-SPE-ATC-10000-0018, Issue 0.2, 15 October 2003 (to be revised)

[AD42] intentionally blank

1.5.4 Safety and Standards

Note: In lieu of DIN standards, equivalent national standards or European directives can be used upon approval from the VPO.

[AD43] *VISTA Project Safety Management Plan*, VIS-PLA-ATC-00001-0019, Issue 2.0 12 April 2002

[AD44] *Document Requirement Definitions Library*, VIS-SPE-ATC-95000-0002m, Issue 0.2, 9 January 2002

[AD45] Eurocode No.8 Structures in seismic regions Design Part 1, Commission of the EC Report, EUR 12266 EN 1988, 1988.

[AD46] General principles for the Safety Design of Technical Products, DIN 31000 (1979-03) including DIN VDE 31000-2 (1987-12), 1987.

[AD47] Safety of machinery - Electrical equipment of machines - Part 1: General requirements, EN 60204-1:1997, 1997.

[AD48] Protection against electrical shock – Common aspects for installation and equipment, IEC 61140, 1997-11.

[AD49] Safety of information technology equipment, IEC 60950, 3rd edition, 1999-04

[AD50] Insulation coordination for equipment within low-voltage systems - Part 1: Principles, requirements and tests, IEC 60664-1, Ed. 1.1, 2000-04

[AD51] Electrical Installation of Buildings, IEC 60364, 2001.

[AD52] intentionally blank

[AD53] Electromagnetic Compatibility (EMC) including Electromagnetic Pulse (EMP) and lightning Protection – Programme and Procedures – Procedures for Systems and Equipment, VG 95 374 Part 4.

[AD54] COSHH Regulations, Framework Directive98/24/EC, 1999

[AD55] Specification for unfired fusion welded pressure vessels, PD 5500:2000

1.6 Applicable Drawings

[AD56] intentionally blank

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[AD60] *Telescope Structure Interface to M2 System* VIS-DWG-ATC-01000-05000, Issue A, 1 May 2002

[AD61] *Instrument Interface to Telescope*, VIS-DWG-ATC-06000-01000, Issue B, 16 Oct 2002.

[AD62] *Mechanical Interface with Cassegrain Focus Instrument*s, VIS-DWG-ATC-06000-04000, Issue B, 16 Oct 2002.

[AD63] *Telescope Interface to Instrument Handling Equipment*, VIS-DWG-ATC-01000-06130, Issue A, 23 April 2002.

1.7 Reference Documents

[RD01] *VISTA Operational Concept Definition*, VIS-SPE-VSC-00000-0002, Issue 1, 28 March 2001.

[RD02] *VISTA Instrument Software Requirements*, VIS-TRE-ATC-00150-0003, Issue 2, 28 Sept. 2001.

[RD03] *Data Flow System High Level User's Guide*, VLT-SPE-ESO-19000-1780, Issue 2, 7 July 2001.

[RD04] *IR Instrument Conceptual Mechanical Design*, VIS-TRE-ATC-00120-0002 Issue 1, 4 October 2001.

[RD05] *Final Lay-out of VLT Control LANs*, VLT-SPE-ESO-17120-1355, Issue 1.2, 12 January 1999.

[RD06] *Temperature Requirements for the VISTA Cryostats*, VIS-TRE-ATC-00180-0003, Issue 2.0, 20 September 2001.

[RD07] *Systems Image Quality Budget*, VIS-TRE-ATC-00002-0001, Issue 3, 3 Oct. 2001.

[RD08] *Filter Wheel Geometric Requirements*, VIS-TRE-RAL-06051-1001, Issue 0.3, 9 September 2002.

[RD09] *Near IR Wavefront Sensing for Gemini*, TN-PS-G0031, Fred Gillett, August 1995.

[RD10] *Analysis of the Paranal Weather Archive, VIS-TRE-RAL-06012-0001, Issue 1.0, 2 May 2003.*

2 DESCRIPTION

VISTA will be a 4m diameter telescope dedicated to imaging surveys in the visible and near infrared. It will be located in Chile at the Cerro Paranal Observatory site of the European Southern Observatory (ESO). It will be operated and maintained by ESO staff.

Initially the IR Camera will be the only scientific instrument used with VISTA, but a later Visible Camera will be interchangeable with the IR Camera, instrument changes being a daytime operation.

Quality assessment will be performed on the data at the telescope site. Data will be shipped to Europe for final data reduction, archiving and distribution.

3 SYSTEM REQUIREMENTS

3.1 Introduction

The overall requirements for the Infrared Camera, considered as a single system, are described in this section. These requirements are closely related to the Infrared Camera specification in the VISTA Technical Specification. There are some clarifications and further details, but no subsystem details (these are described in Section 4).

3.2 Design Continuity

The final design of the IR Camera shall be an evolution or finalisation of the design presented and accepted at the Preliminary Design Review.

3.3 Location

The Camera shall be mounted on the Cassegrain Rotator. Certain subassemblies may be located elsewhere in the VISTA Enclosure, e.g. handling equipment or in the VLT Control Building, e.g. the Instrument Workstation.

3.4 Reference Frame Definition

The co-ordinate system requirements detailed in [AD05] shall be applied to all levels of VISTA. Local co-ordinate systems linked to telescope, telescope assemblies and other parts of VISTA may be defined as necessary, taking into account the requirements of [AD05].

3.5 External Interfaces

3.5.1 Telescope Structure

The mechanical interface between the Cassegrain Rotator and the Camera is prescribed in [AD37] and [AD62].

3.5.2 Optical Interface with Telescope

The optical interface between the Telescope and the Camera is defined in [AD36].

3.5.3 Services

The provision of services to the Camera is defined in [AD37], [AD38] and [AD40].

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3.5.4 Telescope Control Software

The IR Camera shall interface with the Telescope Control Software to transfer the following data:

Data	Camera Module	TCS Module	Direction	Ref.
Guide signals	Guide Sensor	Tracking or Axis Control TBD	Camera → TCS	ICD [AD33]
Optical aberrations at two points in focal plane	LOWFS	Active Optics	Camera → TCS	ICD [AD33]
High Resolution WaveFront Measurement	HOWFS	Active Optics	Camera → TCS	Camera → TCS
Telescope commands	Observation Software	Telescope Interface Module	Camera → TCS	TCS User Manual [AD31]
Telescope status	Observation Software	various	TCS → Camera	TCS User Manual [AD31]

3.5.5 Higher Level Software

The IR Camera shall receive Observation Blocks from the higher level software viz. P2PP, BOB and the schedulers. This interface is formally described in the ICD [AD34]. In practice, it is defined in the software templates provided by ESO [AD25].

3.5.6 Data Handling

The data produced by the Camera, e.g. science data, calibration data and logs, will be passed to the Data Handling System. This interface is formally described in the ICD [AD35]. In practice it is defined in the software templates provided by ESO [AD25].

3.6 Environmental Conditions

3.6.1 General

The equipment shall comply with the requirements defined in the VLT Environmental Specification [AD06], unless specifically amended by the requirements defined herein. This document describes the overall environmental conditions to be expected in operation, maintenance and storage at the Chilean site and transportation from Europe.

The Camera design shall consider the effects of environmental conditions combined with operational parameters in consideration of stress and fatigue life. The required load combinations and allowable stresses are defined in Section 5.

3.6.2 Transportation Environment

The transportation environment defined under Section 4.1 of [AD06] is applicable.

3.6.3 Installation, Operation and Maintenance Environment

The environment defined under Section 4.2 of [AD06] is applicable except for that specified herein.

3.6.3.1 Natural Temperature

Operational temperature range is defined as the ambient air temperature under which all performance requirements shall be met. It is defined as:

Operational temperature range 0 to 15 °C

Functional temperature range is defined as the ambient air temperature under which it shall be possible to operate the system although with degradation of performance[1]. It is defined as:

Functional temperature range -5 to 25 °C

3.6.3.2 Natural Wind

Operational wind speed

The IR Camera shall be able to operate within its nominal performances, achieving the image quality defined in Section 3.14, for internal wind speed up to v = 9 m/s mean with 2m/s rms turbulence and gusting. This internal wind speed is assumed to correspond to an external wind speed of 18m/s above which observation shall be stopped and the dome closed.

Survival wind speed

Each subsystem of VISTA shall be dimensioned for the relevant expected wind speed, taking into account the requirement of Section 4.2.9.1 of [AD06] including possible accidental condition. In case the Enclosure cannot be closed, parts of the telescope may be exposed to stronger wind than the operational wind speed.

[1] Degraded performance is defined as being suitable performance to test all systems functionality but the quality of data from the science detectors is not important and will not be archived.

Unless otherwise substantiated by proper design and/or analysis the survival wind speed to be used for the dimensioning of equipment inside the VISTA enclosure shall be v = 36 m/s.

3.6.3.3 Earthquakes

Two design earthquakes are defined by the requirement of [AD06] Section 4.2.14: The Operating Basis Earthquake (OBE) and the Maximum Likely Earthquake (MLE). The excitation characteristics shall be in accordance with [AD07].

If the minimum excitation frequencies meet the requirements of [AD07], the following global accelerations can be applied as earthquake loading to the Camera (TBC[2]):

	α_{radial}	$\alpha_{tangential}$
OBE	1.8g	1.8g
MLE	2.4g	2.4g

For the purpose of hazard evaluation see Section 3.28.4.

3.6.3.4 Humidity

1. The design goal for the IR Camera is that the camera should meet the operational requirements within the humidity range 0% to 80% when the temperature is within the "operational range" defined in Section 3.6.3.1 without misting of the window. Following the analysis of [RD10], however, it is clear that this goal may be relaxed significantly without incurring a substantial amount of lost observing time due to humidity. The specification is therefore that the camera should be designed so that no more than three nights observing time shall be lost each year, relative to the above goal, due to humidity alone. This requirement shall be verified by analysis. This allocation shall include the recovery time of 30 minutes waiting for the humidity to stabilise following each wet period.

2. When the temperature is within the "functional range" defined in Section 3.6.3.1, but outside the "operational range", the humidity range within which the camera is capable of operation without misting of the window shall be determined and notified to the telescope operator.

3.7 Physical Characteristics

1. The mass of the Camera shall be 2700 ± 200 kg.
2. [AD61] prescribes:
   (a) the allowable space envelope
   (b) the centre of gravity location and tolerance of the cameras
   (c) inertial requirements (tolerance on the inertia shall be consistent with the variation of the location of the centre of gravity and variation in mass)
3. The Work Package shall maintain a mass, mass moment and inertia budget.

[2] The values of OBE and MLE are based on the preliminary analysis of the telescope conceptual design. These values will be confirmed following the telescope PDR.

3.8 Electromagnetic Compatibility

3.8.1 General

3.8.1.1 Intra-system electromagnetic compatibility

1. The Camera shall exhibit complete electromagnetic compatibility among the parts, components, devices, apparatus and equipment of which it is composed (intra-system electromagnetic compatibility).

2. No malfunction, degradation of performance or deviation from specified parameters is permitted because of lack of intra-system electromagnetic compatibility.

3.8.1.2 Inter-system electromagnetic compatibility

Minimisation of the electromagnetic interference between the Camera and its environment shall be a concern in the design and manufacture of the Camera (inter-system electromagnetic compatibility). In order to achieve inter-system electromagnetic compatibility. The Camera shall comply with the EMC requirements set by the applicable documents [AD08] and [AD10].

The following sections 3.8.2, to 3.8.3.5 explicitly highlight the EMC requirements of [AD08] and [AD10] applicable to the Camera.

3.8.2 Electromagnetic Environment

The Camera will be installed, operated and located within the electromagnetic environment specified by [AD08] and therefore, shall comply with the requirements imposed by [AD08].

Definitions:

1. The Camera shall be considered part of the VLT Observatory. Therefore the general requirement of the VLT observatory are applicable.
2. For the purpose of this Specification, the requirements applicable to the Telescope Area of the VLT Observatory are to be intended as fully applicable to the VISTA Telescope Area.

As a minimum this entails the following requirements (The following list is simply to be intended as a reminder of such requirements and not a waiver to [AD08].):

- Earthing and equipotential bonding shall be realised at the VISTA telescope Area
- The Camera including its subsystems and in general all the internal equipment shall be protected against lightning electromagnetic pulse (LEMP). The requirement of the Telescope Area are applicable.
- The Camera shall be protected against overvoltages

- Power insulation used shall be according to the principals and requirements of national standards, taking into account the altitude of VISTA
- The VLT power system is expected to provide electric power with the quality specified by Chapter *4. "PERFORMANCE REQUIREMENTS*" of [AD08]

3.8.3 Emission

Note. In the present subsection and in the following one (§ 3.8.3.5), the term "port" is used according to the definition given by the European Standards CENELEC EN 50 081-1:1992 and EN 50 082-1:1992, viz.,

"port": particular interface of the specified apparatus with the external electromagnetic environment.

The Camera shall comply with the emission limits specified by the [AD10].

3.8.3.1 Radiated Emission

The electromagnetic radiation (radiated field) emitted by the Camera shall comply with the limits imposed by subsection 4.1.2 (resp. § 4.1.3) of [AD10].

3.8.3.2 Conducted Emission (Disturbance Voltages)

The terminal voltage emitted by the Camera at its input (and output, if any) AC power ports (AC mains) shall comply with the limits imposed by subsection 4.1.2 (resp. § 4.1.3) of [AD10].

3.8.3.3 Conducted Emission (Harmonic Currents)

The Camera shall not emit at its input (and output, if any) AC power ports, harmonic currents in excess of those specified by subsection 4.1.5 of [AD10], i.e., of those standardised by IEC 555-2.

3.8.3.4 Conducted Emission (Voltage Fluctuations)

The Camera shall not introduce at its input (and output, if any) AC power ports, voltage fluctuations in excess of the limits specified by subsection 4.1.5 of [AD10], i.e., of those standardised by IEC 555-3.

3.8.3.5 Immunity

The Camera shall comply with the applicable immunity limits specified by the [AD10]

Such compliance implies immunity to the disturbances detailed in the following. The immunity limits referred to are those specified by the [AD10].

3.8.3.6 Input (and output, if any) AC power ports

Disturbances	Immunity limits and performance criteria
Harmonic voltages (individual harmonics and THD)	see item 4.2.2.1 and 4.2.2.2 of [AD10]
Voltage fluctuations	see item 4.2.3.1 of [AD10]
Voltage dips and interruptions	see item 4.2.4.1 and 4.2.4.3 of [AD10]
Voltage (current) surges	see item 4.2.5.1 of [AD10]
Fast transient bursts (applied also to PE terminals)	see item 4.2.6.1 of [AD10]

3.8.3.7 Control, Signal Ports

Disturbances	Immunity limits and performance criteria
Fast transient bursts	see item 4.2.6.3 of [AD10]
50 Hz voltage on control/signal lines	see subsection 4.2.1 1 of [AD10]

3.8.3.8 Enclosure Port

Disturbances	Immunity limits and performance criteria
Electrostatic discharge – ESD	see subsection 4.2.8 of [AD10]
50 Hz magnetic field	see subsection 4.2.9 of [AD10]
Radiated electromagnetic field	see subsection 4.2.10 of [AD10]

3.8.3.9 Input and Output DC Power Ports (if any)

Disturbances	Immunity limits and performance criteria
Voltage fluctuations	see item 4.2.3.2 of [AD10]
DC voltage dips	see item 4.2.4.2 of [AD10]
Voltage (current) surges	see item 4.2.5.2 of [AD10]
Fast transient bursts	see item 4.2.6.2 of [AD10]

3.9 Electrical Isolation

All internal circuitry shall be isolated from the chassis or case as required to produce the noise performance figures in Section 3.17.

External case and chassis bonding shall comply with the requirements of [AD08].

3.10 Vibration

The effects of vibration shall be kept to a minimum through good engineering practice and operational considerations. For example, vibration sources shall be adequately isolated or damped or, where appropriate, mounted off the telescope.

The Camera's performance shall be achieved with potential sources of vibration associated with the Camera in all their normal operational states.

3.11 Thermal

3.11.1 External

(a) Any external surface below the Cassegrain Rotator Interface shall have a temperature that differs by less than +1.5°C / -5°C from the ambient air. This assumes 1m/s wind speed within the open dome and the telescope pointing to zenith. This requirement shall be met with ambient air variation of +/- 0.5°C.

(b) With the exception of the cryostat window, any external surface above the Cassegrain Rotator Interface shall have a temperature that differs by less than +1.5°C / -3°C from the ambient air. This assumes 2m/s wind speed within the open dome and the telescope pointing to zenith. This requirement shall be met with ambient air variation of +/- 0.5°C.

(c) All concentrated heat sources generating > 100 W shall be cooled.

(d) Dispersed heat generating systems with combined heat sources of 200 W shall be actively cooled.

(e) The temperature of the external surface of the cryostat window shall be compatible with the humidity requirements of Section 3.6.3.4

(f) The temperature of the external surface of the cryostat window shall be ≥ ambient temperature – 3.5 °C.

(g) Internal and external temperature sensors shall be provided at appropriate locations for monitoring and calibration purposes.

(h) The telescope side of the Cassegrain Rotator Interface may be assumed to follow ambient temperature.

3.11.2 Internal

(a) Temperatures of lenses and detectors shall be such as to meet the relevant performance requirements.

(b) The total flux reaching the focal plane from emission within the cryostat shall be ≤ 0.3 photons/s/pixel with any filter. This shall assume that the filters are transparent at all wavelengths for off-axis angles > 30 degrees, and the actual long-wavelength detector cutoff as specified in [AD01].

(c) The thermal design shall take account of emission from the cryostat reaching the focal plane by reflection in M2.

3.12 Wavelength Coverage and Throughput

(a) The Camera shall operate over the passbands indicated in Table 3.1 with the indicated minimum throughput. This Camera Throughput includes the effects of windows, lenses and filters, but not those of the detectors, the telescope or the atmosphere.

Band	Y	J	H	K_S	K
Nominal Centre Wavelength (μm)	1.02	1.25	1.65	2.15	2.20
Nominal Bandwidth FWHM(μm)	0.10	0.20	0.30	0.30	0.41
Minimum Camera Throughput	0.74	0.74	0.74	0.81	0.81

Table 3.1: Passbands and throughput

(b) In addition, the throughput of window + lenses only (**excluding** filters) shall exceed 80% between 750 – 850nm and shall exceed 85% between 850 nm to 1μm. (This is for reasons of both wavefront sensing and future provision of a Sloan z science filter).

Notes

(i) Detailed filter specifications are in Section 4.3.1.

(ii) The Y band is the same band formerly known as Z_{IR}.

3.13 Elevation

(a) The Camera shall operate over the altitude range 90° (optical axis pointed at zenith) to 20°.

(b) The Camera shall operate at any roll angle on the Cassegrain Rotator.

(c) The Camera shall be able to be rotated into any orientation without incurring damage.

3.14 Image Quality

3.14.1 Camera Image Quality Description

The basic philosophy of the Camera Image Quality (CIQ) definition is that CIQ is the difference in image quality, in a root-sum-square sense, between the IQ from the real camera and the IQ of a 'perfect' camera with the finally-chosen optical prescription and negligible pixel size.

This should most closely match what can be measured, i.e. the lab image test should reveal optical errors with respect to the camera optical prescription (polishing errors, misalignment, focal plane non-flatness, etc) and extra camera-related terms e.g. flexure, wavefront sensor errors, can be calculated by analysis and added. Pixel size was included in CIQ by request since it occurs in the lab test (though clearly it is a fixed contribution, in fact the largest one).

The 'telescope' aberrations are intentionally excluded from CIQ because they are not reproducible with the lab test. Diffraction is also excluded because it occurs in both the on-paper prediction of the test result and the real test measurement, which are different to get the CIQ term.

The above CIQ definition does not necessarily imply that the finally-chosen lens prescription delivers usable images when combined with the telescope; so, that is covered separately by the requirement in Section 4.4. The result of Section 4.4 is that the Camera consortium may vary the lens prescriptions from the baseline ones if and only if, the resulting image quality on paper is equal to or better than that of the baseline design.

3.14.2 Definitions

(a) The Camera Image Quality (CIQ) is defined as

$$CIQ = \max\left(EED(50\%), \frac{EED(80\%)}{1.54} \right)$$

where EED is the encircled energy diameter measured in arcseconds on the sky for an exposure of duration one hour. (The derivation of this requirement is detailed in [RD07]).

The CIQ includes, *inter alia* the effects of:

- (i) optical imperfections of window, lenses and filters
- (ii) accuracy of mechanical mounting and alignment of all components
- (iii) flexure due to gravity or motion
- (iv) thermal expansion or contraction
- (v) any other mechanical factors
- (vi) detector size and sampling
- (vii) movement of the guide sensor, wavefront sensors and focal plane array with respect to one another

Some of these, e.g. (vi), are not within the control of the IR Camera Consortium, but shall be included within the CIQ budget.

The CIQ excludes the effects of:

- (i) telescope misalignment (i.e. undesired misalignment or movement of M1 and the Camera mounting flange on the Cassegrain rotator, with respect to one another)
- (ii) diffraction effects of the telescope baffles and obscurations
- (iii) geometrical aberration of the telescope, window, field corrector lenses, filters
- (iv) telescope tracking errors
- (v) other internal errors of the telescope
- (vi) atmosphere

The CIQ assumes:

(i) the position of the secondary mirror can be adjusted once every 180s using the correction signal from the low order wavefront sensors.

(ii) the pointing can be adjusted once every 0.1s using the correction signal from the guide sensor.

(b) Airmass is 1/cos(ZD), where the zenith distance ZD is defined by

$$ZD = 90° - altitude$$

3.14.3 Maintenance of CIQ Budget

(i) The Consortium shall construct and maintain a CIQ budget detailing the contributions from the constituent values of the CIQ figure.

(ii) The budget shall take account of values of zenith distance from zero to 70°.

(iii) The budget shall take account of all values of Cassegrain rotator angle.

(iv) The budget shall identify and quantify sources of repeatable and non-repeatable errors. However the values listed in the budget shall be the residual error effects after any correctable effects have been compensated for.

3.14.4 Requirements

The following Image Quality requirements shall be met for an exposure of duration of up to 30 minutes through the J, H and K_S filters:

(a) For an elevation that may vary at a continuous rate of up to 15°/hour within the airmass range 1.0 to 1.3, the image quality shall be:

CIQ ≤ 0.32 arcsec

(b) For an elevation that may vary at a continuous rate of up to 15°/hour within the airmass range 1.3 to 2.9 , the image quality shall be

$$CIQ \leq 0.32 \times \left(\frac{airmass}{1.3}\right)^{0.6} arc\sec$$

3.15 Misalignment and Differential Movement

Defocus, decentre (or translation) and tilt within the Camera and between the Camera and its mounting flange will cause a degradation of image quality. Some of this degradation will be compensated for by the telescope, e.g. by guiding corrections and adjustments to M2.

External compensation can be assumed to

(a) correct optimally the M2 focus and tilt (as measured by the Camera's LOWFSs) once every 3 minutes

(b) correct optimally the pointing (as measured by the Camera's guide sensor) with a closed loop bandwidth of 2 Hz

The CIQ shall take account of the effects of defocus, de-centre and tilt using the sensitivities specified in **Table 3.2**, which lists values separately for compensated and non-compensated errors. Where compensated value is used, clear justification shall be given of where compensation can be performed.

Analysis of the differential movement may treat the Cassegrain Rotator as a rigid body.

	Defocus = 1 μm	**Decentre = 1 μm**	**Tilt = 1 μradian**
Residual after compensation	0.0001 arcsec	0.0003 arcsec	0.0006 arcsec
Without compensation	0.0050 arcsec	0.0005 arcsec	0.0007 arcsec

Table 3.2: The sensitivity of the 50%EED to movement between the instrument mounting flange and the focal plane.

3.16 Distortion

The centre of the pincushion distortion pattern shall remain stable relative to the focal plane within a circle of 180 μm radius.

3.17 Noise

3.17.1 Detector and Controller Specification

The detectors and controllers are being purchased by the VPO and will be "free issued" to the IR Camera Consortium. The detectors will meet the requirements of [AD01]. The controllers will meet the requirements of [AD02].

3.17.2 Read Noise

Camera read noise shall be less than 32e$^-$ rms with a double correlated sampling (see 4.1.2) at a speed that allows a full readout within 1 second and achieving > 100ke$^-$ full well capacity.

3.17.3 Dark Current

The dark current shall be < 8e$^-$ /s/pixel.

3.17.4 Glow

The on-chip glow due to the multiplexer circuitry (both on-chip amplifier glow and shift register) shall not contribute more than 80 electrons to a 10 second integration using double correlated sampling.

3.17.5 Crosstalk

The crosstalk between the various readouts shall be < 0.005%. If one of the detector readouts processes a bright signal corresponding to full well capacity, then the cross talk to any other channel (shadows of the bright signal) being processed at the same time shall be < 0.005%.

3.17.6 Noise as Function of Exposure Time

The power spectrum of the system noise shall be such that coadding images measured through a broad band filter shall improve the S/N as $(\text{time})^{0.5}$ between 15 minutes and 16 hours within any two month period under the same operating conditions[3] to within 10%.

3.18 Stray and Scattered Light

3.18.1 Sky Brightness Definitions

Values for sky brightness are assumed in the specifications of background and scattered light levels.

1. The intrinsic dark sky brightness is assumed to be as follows:

Band:	J	H	K_S
Mag's/sq. arcsec	16.0	14.1	13.0

2. The intrinsic sky brightness at Full Moon is assumed to be as follows:

Band:	J	H	K_S
Mag's/sq. arcsec	16.0	14.1	13.0

3. For purposes of calibration observations, the sky brightness immediately before sunset and immediately after sunrise shall be assumed to be 9.9 mag's/sq. arcsec in the K_S band [RD09].

3.18.2 Scattered Light

1. Light scattered from a 1st magnitude object 1.5° from the centre of the field shall not contribute >50% additional light over and above the dark night sky background.
2. For the IR Camera, the contribution to detector background from 'locally scattered'[4] light, in J, H and Ks filters, shall not exceed 5% of the 'natural sky' background at any angle ≥ 25˚ from the Full Moon; and it should not exceed 50% of the natural sky value at angles 15˚ - 25˚ from the Full Moon.

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[3] The same operating conditions include such parameters and cleanliness of the mirrors, airmass and moon proximity.

[4] Locally scattered light is defined as all moonlight scattered from any surface within the dome, telescope structure, mirrors or camera, based on the telescope and enclosure conceptual designs (moonlight scattered in the atmosphere is excluded). The final design of the enclosure and telescope structure is still TBD and outwith control of the camera consortium. Should the design of these sub-systems change significantly, the VPO will be responsible for ensuring the performance is maintained.

3. For the purpose of this calculation, the integrated brightness of the Full Moon shall be assumed to be:
   J = -13.8
   H = -14.0
   K_S = -14.1
4. This calculation shall assume that the Moon and telescope are at equal elevations and 180 degrees apart in azimuth. Calculations shall include an approximate model of the dome and its movable moonscreen, which may be partly closed but should not vignette the beam. (NB: Scattering from the moon shining into the cryostat is likely to dominate if it occurs).

3.18.3 IR Thermal Rejection

Preamble: Due to the lack of a cold stop in the camera design, the camera baffles must provide highly effective rejection of unwanted emission from ambient-temperature surfaces outside the beam. This is critical to camera performance especially in the Ks band. (Though this band is in the tail of the room-temperature black-body curve, emission from ambient-temperature surfaces nevertheless greatly exceeds the natural sky brightness in Ks band).

Definition:
The effective emissivity of the camera is defined as the flux in the Ks band reaching the focal plane which originated from outwith the optical beam, divided by the value in the same band for a black secondary mirror (subtending solid angle 0.079 sterad) at ambient temperature.

This shall **include, but not be limited to:**
1. Thermal emission from all surfaces outwith the optical beam reaching the focal plane via any route, including scattering from the cryostat baffles and lenses and/or reflection in the M2 baffle, M1 and M2 and/or any combinations thereof.
2. Thermal emission from the interior of the cryostat (expected to be small).
3. Thermal emission from the upper end of the cryostat reflected in M2 or the M2 baffle.
4. Thermal emission from the M2 baffle (to be calculated assuming baffle emissivity 2% and the appropriate solid angle).
5. Thermal emission from the camera window.

This shall **exclude** 'unavoidable' emission i.e. the following:

1. Emission from the sky in the beam
2. Thermal emission from the primary and secondary mirrors.
3. Thermal emission from the telescope vanes[5] reflected via M1 and M2.

The following assumptions may be made for the emissivity calculations

1. Ambient temperature of 15° C shall be assumed if necessary (though, for wavelength-independent effects, this will cancel out via the definition).

[5] The vane design is defined in [AD60] for the Telescope Technical Specification. This design will change during the telescope design development, however these changes should not impact the thermal analysis.

2. The surfaces of M1 and M2 shall be taken as clean and fresh coated, for the purposes of calculation.
3. The IR Camera external window shall be taken as clean, for the purposes of calculation.
4. Surfaces inside the IR Camera shall use the expected properties of the design, including estimated degradation of coatings.

Requirement: The effective emissivity of the camera shall be < 4%.

3.18.4 Ghosting

Ghosting is defined as image artefacts caused by multiple reflections of objects in the field of view. For the IR Camera:

1. Ghosting with up to two unwanted reflections shall not generate any images with diameter ≤ 75 arcsec.

2. From a 6^{th} magnitude star at any point in the field, the proportion of detector pixels in the focal plane that receive ghost flux exceeding 50% of the dark sky background shall be ≤ 0.1%.

3.18.5 Light Leakage

The increase in background light due to leakage of light that bypasses the science filters shall be < 0.1%. The increase in background light in the broad band filters (YJHK) due to light in the science beam that is scattered through the filters at high incidence angles shall be < 2.5% of the in band sky brightness for the Y band and < 1% of the in band sky brightness for JHK.

3.18.6 M2 Baffle Development

The design and implementation of the M2 Baffle is critically dependent on the final design of the IR camera. There are conflicting needs between maximising throughput, curvature sensing sensitivity and achieving a fully baffled system. The VPO is committed to optimise the baffle design following the IR Camera Preliminary Design Review. This shall include optimisation between the Baffle geometry, investigation of increases in diameter on curvature sensing and partial vignetting of the edge of the field. Any such changes will be subject to review as part of the IR Camera final design development.

3.19 Exposures

3.19.1 Detector and Controller Specification

The IR detectors and their controllers are being purchased by the VPO and will be “free issued” to the IR Camera Consortium. The detectors will meet the requirements of [AD01]. The controllers will meet the requirements of [AD02].

3.19.2 Exposure Length

It shall be possible to make exposures of any duration between 1s (0.5s goal) and 1 hour, specified as a real number which include fractions of a second.

3.19.3 Exposure Accuracy

(a) The duration of exposures shall be within 0.1s or 1% of that requested, whichever is the larger.
(b) The duration of the exposure at any point in the field shall be recorded to an accuracy of 0.01s or 0.25%, whichever is the larger.

3.19.4 Time Stamping

The absolute timing of each exposure and order of pixel readout shall be recorded so as to permit reconstruction of the absolute UT of mid-exposure at each pixel to ≤ 0.1 s.

3.19.5 Interval between Exposures

It shall be possible to start an exposure sequence within 5s of the completion of the previous exposure sequence, assuming no reconfiguration is required.

3.19.6 Rate of Exposures

It shall be possible to perform data acquisition at a sustained rate of one exposure every 10s over a period of 14 hours, assuming no reconfiguration is required.

3.19.7 Multiple Readouts per Exposure

(a) It shall be possible to execute and process, prior to data storage, multiple readouts per exposure. At least two such modes are anticipated:

(i) Double correlated sampling where the array is reset and a first read is performed followed by a second read after a predetermined delay. Subtracting the first read from the second gives the data frame.
(ii) Read/reset/read sequences as defined in [RD01].

(b) During an exposure it shall be possible to perform individual read-outs at the rate of one every 10s.

3.19.8 Rapid Sequence of Exposures

(a) Looking at the same point on the sky through the same filter, it shall be possible to execute a sequence of exposures such that the delay between completing one exposure within the sequence and starting the next shall be ≤ 1s.

(b) It shall be possible to perform data acquisition and store IR exposures within a sequence at a rate of one every 10s (raw data) or 20s (coadded or NDR data).

(c) The number of exposures within a sequence shall be defined in advance.

(The data cube produced by this process is not an ESO science data product.)

3.19.9 Fast Windowed Readout

For the purposes of occasional calibration and test of the telescope tracking in 3 axes, it shall be possible to read out a small window (15x15 pixels or larger) simultaneously on at least two non-adjacent science detectors (or preferably, three in a row) at a fast rate of 10 Hz (Goal: 20 Hz). This window may be fixed at the same pixel location on both (or all) detectors.

3.20 Calibrations

3.20.1 Calibration Procedures

Calibration procedures shall, where feasible, be implemented in software. These procedures shall:

1. Record all changes so that it is possible to revert to previous calibrations and perform trend analysis.
2. Record all raw data used to generate new calibrations (e.g. FITS files in the archive)
3. Be capable of being initiated and run automatically, whilst remaining under control of the operator.

3.20.2 Calibration Data

The Camera shall acquire and store all data necessary to fully reduce the data including:

(a) dark frame
(b) flat frame
(c) sky frame

These data shall be sufficient to allow the pipeline and quality control software (not part of this Work Package) to derive the following data:

(a) master dark
(b) read noise
(c) dark current
(d) glow
(e) image FWHM and ellipticity
(f) bad pixel masks
(g) gain and non-linearity
(h) sensitivity of each science frame
(i) detector sensitivity
(j) fringing

3.20.3 World Co-ordinates

The Camera shall obtain sufficient calibration information so the position of each detector pixel in an exposure can be mapped onto a corresponding location on the sky. In other words, there needs to be a (chip, column, row) to (RA, Dec) mapping calibration. Such a calibration must take into account the relative positions and orientations of the detector chips. The calibration information shall be stored in a format agreed by the ESO Data Interface Control Board.

3.21 Data Handling

3.21.1 Format and Content

(a) It shall be possible to store data from any of the following forms:
- (i) Raw data
- (iii) Raw data after differencing
- (iv) Coadded differenced data
- (v) Coadded read-reset-read sequence

(b) Any set of data shall be stored in one form only.

(c) All science and calibration exposures shall be stored to disk with adequate meta data to allow subsequent full data reduction. Access to observing and site monitoring logs may be assumed.

(d) All data shall be stored in the format compliant with ESO's Data Interface Control Document [AD23].

3.21.2 Storage to Disk

(a) It shall be possible to store exposures at a sustained rate of one exposure per 10s over a period of 14 hours.

(b) The system shall ensure that adequate free disk space is available to store the data when an exposure is initiated, so long as the maximum data volume per night as stated in Section 4.9.15 is not exceeded. If adequate disk space cannot be made available, e.g. due to an equipment or operational failure, the exposure shall not be initiated.

(c) It shall be possible to store data to disk whilst concurrently moving the telescope and reconfiguring the camera.

3.21.3 On-line Storage

Data from the previous 2 nights shall be stored on-line. On-line storage is defined as storage accessible without physical exchange of media.

3.22 Guiding and Wavefront Sensing

(a) The Camera shall include a guide sensor to generate tracking corrections to feed into the Telescope Control Software. Requirements are specified in Section 4.5.

(b) The Camera shall include two low order wavefront sensors to generate wavefront errors, operating concurrently with science observing, to feed into the Telescope Control Software. Requirements are specified in Section 4.6.

(c) The Camera shall include a method of high order wavefront sensing for off-line calibration purposes. Requirements are specified in Section 0.

3.23 Operation

3.23.1 Control of Equipment

1. It shall be possible to operate all equipment, required for observing and normal calibration procedures, from the VLT Control Building.
2. The IR Camera shall be capable of being operated off the telescope. In this mode it shall not interfere with normal operation of the telescope or with any other instrument mounted on the telescope. Full functionality shall be supported, e.g. interaction with other software systems such as data handling, except where precluded.
3. The IR Camera shall not interfere with the concurrent use of a Visible Camera, one Camera being mounted on the telescope (for operations, maintenance and testing) and the other off the telescope (for maintenance and testing).

3.23.2 Observing Modes

1. The normal method of observing shall be queue scheduling, in which observations are completely specified in advance using a tool generating output compatible with P2PP's output.
2. It shall be possible for an observer at the telescope to control observing directly, e.g. by using a tool generating output compatible with P2PP's output.
3. The Telescope Operator shall be able to override any automatic operation, e.g. to perform authorised over-rides. (Within 60 minutes, 10 minute Goal of a suitably authorised request).

3.23.3 Observing and Engineering Logs

1. All observations, including calibrations, shall be logged.
2. All significant engineering events shall be logged including
   a) telescope motions
   b) camera configurations
   c) faults
3. Logs shall be transmitted during the day following the observations.
4. Logs shall properly take account of non-operating detectors i.e. record that the relevant area of sky has not been observed.

3.23.4 Handling Faults

1. Where feasible, the system shall continue normally to operate in the presence of faults. Such faults may include non-operating detectors.
2. The existence of missing or poor quality data shall be indicated in the data headers.
3. All faults shall be logged. Each log entry shall contain relevant details to help an engineer to diagnose the problem.

3.23.5 Weather Monitoring

1. Weather monitoring data from Paranal Observatory shall be incorporated into the science data headers or the logs that are made available with the science data.
2. As a minimum this shall include seeing monitoring, local temperature and wind speed data.

3.23.6 Readout Noise Pickup

It shall be possible to operate any single mechanism during detector readout for noise pickup testing.

3.24 Lifetime

The IR Camera shall be designed for a minimum lifetime of 25 years of operation, comprising an average 12 hours of observation and 12 hours of stand-by per day. The Camera should wherever possible use material and component selection to meet these requirements. Where this proves impractical, on a case by case basis, the Consortium may propose to the VPO alternative requirements[6].

3.25 Reliability

3.25.1 Rationale

VISTA has been designed from the outset for a two-camera implementation. This would allow any maintenance on the IR Camera to be performed while the telescope was operational with the Visible Camera. Until such a time as the Visible Camera is available, the IR Camera must operate alone. This makes the reliability of the IR Camera critical to the overall efficiency of the observatory. As such the requirements of this section have been tightened to a level which may prove difficult to achieve. The VPO recognise this as an issue and will endeavour with the Instrument Consortium to achieve a balance between reliability, maintainability, design analysis and testing.

3.25.2 Specific Reliability Requirements

A Failure is defined as an event causing complete loss of observing capability and which cannot be recovered by corrective maintenance (including fault identification) in less than 4 hours.

[6] Typical cases where this may be accepted is where longevity of components cannot be proven due to insufficient data (e.g. filter specification).

(a) The IR Camera and support systems shall be ***designed***[7] for a Mean Time Between Failures (MTBF) of 3 years.

(b) As a general rule, a high reliability shall be enforced in the design and manufacturing process by appropriate methodology and review.

(c) Wherever possible, engineering activities shall be planned to coincide with a Primary Mirror coating. (Not part of this Contract)

(d) Choice of materials shall minimise out-gassing.

(e) It shall be possible to flush the closed-cycle cooler He lines and cold heads during out-gassing downtime.

3.26 Turn Around Time

3.26.1 Outgassing Downtime

The IR Camera shall be designed on the basis of one shut down per year from out-gassing. It shall be possible to warm-up and pump the instrument to remove out-gassed contaminants within five days. Out-gassing turn around includes:

- removing the Camera from the telescope
- warming up
- vacuum pumping including baking (if required)
- cooling the Camera down to operating temperature
- re-installation on the telescope
- performing any necessary tests and calibrations

3.26.2 Engineering Downtime

The IR Camera shall be designed on the basis of one shut down per three years for engineering activities. It shall be possible to perform a turn-around of the Camera within 10 days. Engineering turn around includes:

- removing the Camera from the telescope
- warming it up
- opening it up
- closing it up
- evacuation and prolonged vacuum pumping including baking (if required)
- cooling the Camera down to operating temperature
- re-installation on the telescope
- performing any necessary tests and calibrations

[7] It is realised that in a bespoke design, MTBF analysis can be particularly rigorous. The VPO recognise that such analysis may place undue burden of proof on the Instrument Consortium. In lieu of such analysis the VPO will accept a best effort approach to achieving this requirement. In such an approach, choice of material, bearings, lubrication, cyro-mechanisms etc. shall be based on manufacturers' recommendations coupled with in-house expertise and extrapolation from previous successful designs. This approach if adopted shall be documented for agreement with the VPO at or before the PDR and implemented for FDR.

This turn around time does **not** include time required to repair the defect.

3.26.3 Instrument Exchange

It shall be possible to remove the IR Camera from the telescope or install the IR Camera on the telescope within four hours.

3.27 Maintainability

3.27.1 Rationale

The requirements in sections 3.27.2 to 3.27.5 are the standard maintenance requirements for VISTA hardware. It is realised that in some areas of the IR Camera these requirements cannot be realised. The Consortium should use these requirements as guidelines and adopt them where appropriate and identify areas where compliance is prohibitive. The Consortium will propose to the VPO alternative approaches for such areas

3.27.2 Maintenance Approach

ESO will operate VISTA and perform the on-site maintenance. Therefore the maintenance philosophy to be considered during the design of VISTA is the one established by ESO at the Cerro Paranal Observatory. The major elements of this philosophy are as follows:

The maintenance work-load and therefore manpower at the Chilean site shall be minimised and shall be limited as far as possible to preventive maintenance tasks.

Maintenance work shall be performed at system level and by exchange of module (Line Replaceable Units, LRUs) when practical.

1. LRUs are defined as units which can easily (i.e. without extensive calibration, etc) be exchanged by maintenance staff of technician level and that can be easily shipped to a suitable ESO repair location or to an industrial supplier for repair.
2. This concept implies that spare LRUs must be available at the observatory.
3. Standardisation of equipment, fully applicable to VISTA is given in applicable documents [AD08] and [AD11], covering Service Connection Points and Electronic components respectively.

Three different category of maintenance shall be considered:

1. Predictive Maintenance
2. Preventive Maintenance
3. Overhaul

3.27.3 Predictive Maintenance

Predictive maintenance is "condition driven" preventative maintenance. Instead of reliance on life-time statistics, predictive maintenance uses direct monitoring of off the system performance or condition. Typical examples are testing of cooler motor temperature for signs of pump deterioration or monitoring of supply currents for change in loading characteristics. The Work Package shall define the predictive maintenance tasks applicable.

3.27.4 Preventive Maintenance

Preventive maintenance actions shall be planned with a frequency of:

a) Every month for inspections and relatively simple actions of less than 4 hours in total;

b) Multiple of 6 months for other actions with a maximum of 12 hours every 6 months.

The preventive maintenance tasks shall be accomplished by two trained technicians with a minimum of special equipment or tools. The Work Package shall define the preventive maintenance tasks applicable.

3.27.5 On-Site Repair/Corrective Maintenance

On site repair is normally limited to the in-situ exchange of line-replaceable units (LRUs). The faulty LRU will be sent to the ESO repair location or to an industrial supplier for repair.

As a general rule, an LRU replacement or other repair activity shall be accomplished by a maximum of two trained technicians with a minimum of special equipment or tools in a maximum time of 4 hours. Exceptions to this rule will be by agreement with ESO. The Work Package shall define a list of spare parts and propose this list to the VPO. The spare parts will be the subject of a specific contract.

3.28 Safety

Safety is of paramount importance and therefore shall be given appropriate attention during all phases of the work. The requirements with respect to Safety for the VISTA Project are contained in [AD43]. The following list is simply intended as a reminder of such requirements and <u>not</u> a waiver to [AD43].

3.28.1 Hazard Risk Acceptance Criteria

The Work-Package shall perform a hazard analysis in accordance with that required in [AD43].

3.28.3 General Safety Requirements

The general principles of safety design of technical products defined in [AD46] and [AD47] shall be applied.

3.28.4 Earthquake Hazard

For the purpose of hazard evaluation the OBE and MLE shall be classified as Hazard Probability Levels B and C respectively as defined in [AD43].

3.28.5 Mechanical Safety

Transport, lifting, hoisting devices and similar equipment shall be approved by an officially recognised independent verification agency.

3.28.6 Protection against electric shock and other hazards

3.28.6.1 Introduction

The low-voltage electrical installations of the VLT Observatory are designed and erected according to [AD51] (IEC 60364); their system earthing is TN-S.

T - indicates that one or more points of the Supply are directly earthed (for example, the earthed neutral at the transformer)

N - all exposed conductive metalwork is connected directly to an earthed supply conductor provided by the Electricity Supply Company

S - neutral and earth conductor systems are quite separate

3.28.6.2 Safety Compliance

In order to achieve protection against electric shocks and other hazards, the parts belonging to the Work Package supply shall be designed and erected in compliance with the applicable documents [AD47] (EN-60204-1), [AD48] (IEC 61140) and [AD51] (IEC 60364)

3.28.6.3 Electrical and Electronic Equipment

Electrical and electronic equipment to be installed onto VISTA shall comply with [AD43], taking into account the VLT Observatory altitude.

Information Technology Equipment to be integrated into VISTA shall comply to [AD49] (IEC 60950)

3.28.6.4 Bond Corrosion

In order to prevent bond corrosion, pairing of dissimilar metals shall be avoided where possible. Should joints between dissimilar metals be essential, the metals in direct contact shall exhibit the lowest possible combined electrochemical potential (in any case below 0.6 V) and the anodic member of the pair shall be the larger in size of the two.

3.28.7 Pneumatic Safety

Any compressed air piping, including connections of compressed air system shall be designed in accordance with [AD46].

3.28.8 Cooling System Safety

Cooling systems shall be designed in accordance with [AD46].

3.28.9 Software and Safety

Any computer software failure or failures shall not lead to an unacceptable or undesirable hazard risk. Where protection is required, a hardware based implementation shall be provided. For example, mechanical devices shall have suitable end stops and safety covers, and the electronics shall be designed to cut power to the motors directly if an interlock is detected.

3.28.10 Handling, Transport and Storage Safety

The design of the IR Camera work package shall incorporate all means necessary to preclude or minimise hazards to personnel and equipment during assembly, disassembly, test, transport, transport on site and short/long term storage of VISTA and/or parts thereof.

3.28.11 Operational Safety

None of the following cases shall lead to an unacceptable or undesirable hazard risk

- One or two hardware failures
- Partial or complete loss of energy supplied to the IR Camera or subsystems of it
- Emergency braking of the telescope tube
- OBE or MLE earthquakes
- Wind loads

3.28.12 Safety Interlock System

Interlocks shall be implemented wherever necessary to prevent a dangerous situation or to respond to a dangerous situation. Dangerous situations include hazards both to personnel and to equipment. The number and position of interlocks within the scope of the IR Camera Work Package shall be defined during the design phase.

The interlock system shall not rely on the software, nor assume that any software is running on the instrument LCUs or workstations.

4 SUBSYSTEM SPECIFICATIONS

4.1 Science Detectors and Controllers

4.1.1 Detector Specifications

(a) The detectors shall be supplied by the VPO in accordance with [AD01].

4.1.2 Detector Controllers

(a) An ESO IRACE system, provided by the VPO, shall control the science detector arrays and acquire data from them. The controllers shall be in accordance with [AD02].

4.1.3 ESD Protection

All the detectors and the focal plane shall be safeguarded against the electrostatic damage with normal operating/handling procedures.

4.2 Focal Plane Assembly

4.2.1 General

1. The detectors shall be laid out on the focal plane as defined by [AD03]. This consists of 16 detectors arranged in a 4x4 rectangular grid, with spacing of 90% in the camera x-direction and 42.5% in the y-direction, these percentages being relative to the detector active width.
2. The detectors will be mounted in the focal plane by the detector contractor and subject to the requirements of [AD01].
3. The detectors focal plane shall meet the positional requirements of [AD01].
4. The focal plane module shall be used to hold, cool and protect the IR detector arrays and their associated circuit boards, electronics and cables.

4.2.2 Electrical

1. Over-voltage and electro-static discharge protection circuitry shall be used to protect the detectors.
2. Detector and controller non-linearity shall be ≤ 3% before calibration. Detector and controller gain shall vary by ≤ 2% peak to valley across the full range of operating temperatures.
3. Electrical Crosstalk between any pair of pixels separated by ≥ 10 pixels shall be $< 5 \times 10^{-5}$ (goal 1×10^{-5}).

4.2.3 Co-planarity

Note: the following requirements are derived from astrometric requirements in the VTS. They may also contribute to the CIQ Budget, which may lead to a tighter specification. However, irrespective of the CIQ Budget details, the following requirements shall still apply.

1. All pixels within all the detector arrays shall be contained within two planes spaced by 50 μm across the focal plane.

2. The tilt relative to the focal plane of any one detector array shall remain stable within 0.0125 deg. for the duration between any engineering work on the focal plane.

Thermal Expansion

Differential thermal expansion between the arrays in the focal plane, leading to distortion of the array during operation shall be ≤ 4.5 μm.

4.2.5 Flexure

Differential flexure between arrays in the focal plane under stable temperature conditions shall be

≤ 3 μm laterally
≤ 30 μm axially

4.3 Filters

4.3.1 Filter Specifications

1. Filters covering the full focal plane shall be provided with the characteristics at the operating temperature listed in Table 4.1.

Band	Y	J	H	K_S
Centre Wavelength (μm)	1.02	1.25	1.65	2.15
Tolerance	±0.5%	±0.5%	±0.5%	±0.5%
Bandwidth FWHM (μm)	0.10	0.20	0.30	0.30
Tolerance	±5%	±5%	±5%	±5%

Table 4.1: Filter Passbands

2. The physical dimensions of the filter wheel and optical thickness of the science filters, shall be such as to permit later installation of narrow-band filters (not part of this work package).
3. Throughput of the filters shall allow the system throughput as defined in Section 3.12 to be achieved.

4.3.2 Additional Filters

The system shall permit the later inclusion of the 'additional' filters specified in Table 4.2. (To be included in the ITT for filter procurement as an extra-cost option. It is not a requirement for the Consortium to purchase them, but it shall ensure they are feasible and obtain quotations).

Band	Z_{Sloan}	Pa β	Br γ	K
Centre Wavelength (μm)	0.90	1.282	2.168	2.20
Tolerance	±0.5%	±0.3%	±0.3%	±0.5%
Bandwidth FWHM (μm)	0.14	0.020	0.033	0.40
Tolerance	±5%	±20%	±20%	±5%
Minimum throughput	70%	70%	70%	70%

Table 4.2: Passbands and throughput for additional filters

4.3.3 Filter Exchange

4.3.3.1 Number of Filter Sets

(a) The Camera shall be able to accommodate at one time not less than 8 filter sets: 7 science and 1 opaque.

(b) These must be exchangeable so that any 7 of the eventual complement of science filters may be installed (after opening the cryostat). This exchange shall be made with the IR Camera warm and off the telescope.

(c) If less than 7 science filtersets are initially supplied with the Camera, the remaining slots shall be filled with additional opaque filters.

(d) At least 10 'blank' filtersets shall be provided: these shall be structures mechanically identical to the science filter sets within tolerances, but leaving open space for later insertion of science filter glass elements. Note: the 4 baseline filters do not count towards this 10; any additional filters supplied under Section 4.3.3.7 do count, and additional opaque filters under (c) above also count if and only if they are modifiable to hold science filter glass.

(e) The opaque filter shall be housed in a duplicate filter holder and in all physical dimensions conform to the science filter design.

4.3.3.2 Access for Manual Replacement of Filters

The filter holders shall be accessible via ports on the filter wheel housing, radiation shield and vacuum vessel in order to allow filter holders to be changed without complete disassembly of the entire camera and without disturbance to the focal plane.

4.3.3.3 Duty Cycle

In calculating the lifetime of components it shall be assumed that the filter exchange mechanism operates once every 30 minutes moving half a revolution.

In calculating thermal performance it shall be assumed that the filter exchange mechanism operates once every minute moving one quarter of a revolution.

4.3.3.4 Position Repeatability

(a) Axial <0.5mm
(b) Lateral <0.1mm

4.3.3.5 Speed and Direction of Exchange

(a) adjacent filters <25s.
(b) any filters <60s

It shall be possible to rotate the filter wheel in either direction. (This is so that, given a suitable ordering of filters in the wheel, exchanging between two narrow-band filters does not require crossing a broad-band filter.)

4.3.3.6 Control

Control of the filter mechanism shall be implemented using hardware that conforms to one of the supported configurations in [AD22]. (See also Section 4.9.6.)

4.3.3.7 Mini-filters

It is likely that, in order to meet requirements for calibrations such as HOWFS and/or tracking tests and/or seeing measurements, additional ‘mini-filters’ covering only one or a few detectors may be located in approximately 4 intermediate positions of the filter wheel, in between the 8 main science filter positions. Details of such mini-filters are given in [RD08]. If so, light through the mini-filters shall not fall on the science detectors when any science filter is in use. (When mini-filters are in use, it is permissible for light from adjacent science filters to fall on some detectors).

4.4 Optics

The Telescope Layout with the conceptual design of the instrument is shown in **Figure 4.1.**

1. The optical prescription for the M1 and M2 are frozen and defined in [AD36].
2. The nominal design of the field corrector shall meet the image quality defined 'as designed image as defined in Table 4.3 when it is integrated with the telescope and a central obscuration of 1.6 m:

Band		Y	J	H	K_S
50% eed (arcsec)	on –axis	0.22	0.21	0.16	0.18
	1 deg.	0.26	0.26	0.23	0.26
	1.65 deg.	0.23	0.25	0.29	0.35
80% eed (arcsec)	on-axis	0.46	0.45	0.37	0.44
	1 deg.	0.44	0.44	0.45	0.47
	1.65 deg.	0.46	0.49	0.54	0.70

Table 4.3: As Designed Image Quality

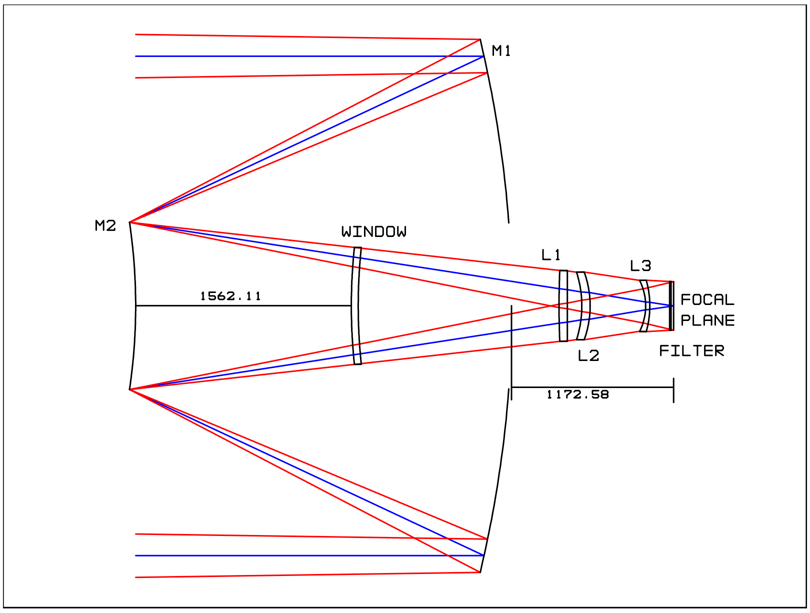

Figure 4.1: Optical Layout of Telescope and Conceptual Design of the IR Camera.

4.5 Guide Sensor

4.5.1 Guide Sensor Operation

The Guide Sensors shall operate concurrently with science observations. The sensor shall be fixed but shall cover a large area, so that there will be a high probability that it sees a usable star. Software within the IR Camera software shall allow a suitable guide star to be selected.

4.5.2 Guide Sensor Requirements

a) A guide sensor with associated controller (as defined in 4.5.3) and software (as defined in 4.5.4) shall be provided.
b) The sensor shall be located in such a manner that it exploits the peripheral sectors of the focal plane.
c) The sensor and any equipment associated with it shall not vignette the science detectors.
d) The guide sensor shall operate concurrently with science observations.
e) The sensor shall cover a large area, so that there will be a 99% probability of finding usable guide star, for a random telescope pointing in the region of Galactic Pole at Full Moon.
f) Sample rate ≥10Hz.
g) Centroid accuracy ≤0.04 arcsec rms per sample.
h) It is highly desirable that the guide sensor should be able to operate 30 minutes after sunset, (e.g. reducing the effective integration time) if the telescope pointing is chosen so that a suitably bright guide star is available.
i) The guide sensor shall be operational within 1 second of receiving the guide star position, assuming that the guide star is within 3 arcsec of its predicted location.

4.5.3 Guider Detector Controller

The guide sensor CCD shall be controlled by an ESO compliant detector controller, e.g. Technical CCD Controller, Next Generation Technical CCD Controller or FIERA. These controllers may also control the low order wavefront sensors and the high order sensor.

4.5.4 Software Functions

Software and hardware on which to run it shall be provided to:
(a) read out the CCD using definable parameters, including frame rate, pixel rate, area of interest
(b) measure metrics (value and error) of the guide star, including (x,y) co-ordinates, integrated flux above background, FWHM, eccentricity, PA of major axis, seeing estimate
(c) log the guide star metrics
(d) plot the guide star metrics on a workstation
(e) send a guide signal to the telescope software, as defined in [AD33], at a rate of up to 10 Hz.
(f) The software shall run on the Guiding Workstation, the Guide Sensor Detector Controller and the Image Analysis LCU (Section 4.9.15).

(g) The guide sensor may skip a single 'beat' during readout of a wavefront sensor. This shall cause the guide signal to remain static and shall not cause a discontinuity. The guide sensor shall not miss more than one beat in any 0.5 s interval.
(h) VLT software shall be used wherever appropriate.
(i) The guide sensor shall be operational within 1 second of receiving the guide star position, assuming that the guide star is within 3 arcsec of its predicted location.
(j) There is no requirement for non-sidereal guiding, but the software shall be designed in such a way as not to preclude the addition of such a mode at a later date.

4.6 Low Order Wavefront Sensor

4.6.1 Low Order Wavefront Sensor Operation

The Low Order Wavefront Sensors (LOWFS) shall operate concurrently with science observations. The sensors shall be fixed but shall cover a large area, so that there will be a high probability that each sensor sees a useable star. Software within the IR Camera software shall allow two suitable guide stars to be selected, one for each sensor.

4.6.2 LOWFS Requirements

The requirements for the LOWFS are:
a) Two LOWFS with associated controller (as defined in 4.6.3) and software (as defined in 4.6.4) shall be provided.
b) Each LOWFS shall be located in such a manner that it exploits the peripheral sectors of the focal plane.
c) The sensor and any equipment associated with it shall not vignette the science detectors.
d) As far as practical the two LOWFS shall be diametrically opposed on the fov.
e) The LOWFS shall operate concurrently with science observations.
f) A frame rate of once per 40 s, or longer (depending on telescope dither rate – but sensors must be able to function at 1 telescope dither per 40 sec)
g) Defocus, astigmatism, coma and trefoil each measured to an accuracy of 30 nm rms in 40s, assuming that each aberration differs from its nominal value by <= 120nm rms. Averaging of consecutive frames over a 3-minute elapsed time interval (assuming telescope aberrations are constant) shall give 20nm rms. These errors include all sources within the LOWFS system, e.g. photon noise from star and sky, readout noise, flexure within the sensor, thermal distortion and WFS algorithms. (Flexure between the sensors and the focal plane shall be accounted for in the CIQ budget.)
h) LOWFS should meet the above 30nm accuracy spec given atmospheric seeing conditions up to 0.75" FWHM. For seeing between 0.75" and 1.5", the LOWFS accuracy should be 30nm * (seeing / 0.75"). For seeing above 1.5", sensor should measure Z4 (focus) to 75nm, but there is no requirement to measure Z5-Z10.[8]
i) In the event that low-order aberrations differ from their nominal value by up to 300nm rms, the system in closed-loop shall converge to the required error above in 2 iterations. In the event that aberrations differ from their nominal value by up to 1000nm rms, the

[8] The PDR design has been assessed with seeing of 0.6 arcsec FWHM. The VPO has accepted for this analysis as proof of design at PDR, the requirement will be investigated post PDR.

system in closed-loop shall converge to the required error above in 3 iterations. This should assume that the M2 Unit and M1 actuators can perfectly deliver any requested change in wavefront.

j) The sensor shall cover a large area, so that there will be a 99% probability of finding usable star in each sensor in the region of Galactic Pole at Full Moon.
k) The start and end of exposure on the two CCDs of one sensor shall be coincident within 1s.
l) Exposures on the two different sensors shall be coincident within 3 s.
m) The Zernike coefficients shall be available to the TCS within 15 s of completion of the exposures.
n) Any overhead imposed on science observations by LOWFS operation shall not exceed 0.5 s per LOWFS frame. (For example, LOWFS should be slaved so as to not interfere with science readouts and telescope dithers, anticipating where necessary).

4.6.3 LOWFS Detector Controller

The LOWFS CCDs shall be controlled by one or two ESO compliant detector controllers, e.g. Technical CCD Controller, Next Generation Technical CCD Controller or FIERA. These controllers may also control the guide sensor and the HOWFS.

4.6.4 LOWFS Software Functions

Software and hardware on which to run it shall be provided to:

(a) Read out the CCDs using definable parameters, including frame rate, pixel rate, area of interest.
(b) Determine the wavefront incident at each sensor using appropriate coefficients, e.g. Zernike or quasi-Zernike.
(c) Log the wavefront coefficients.
(d) Plot the wavefront coefficients on a workstation as a function of time.
(e) Transmit the wavefront coefficients to the telescope software [AD33].
(f) The software shall run on the Guiding Workstation, the LOWFS Detector Controller and the Image Analysis LCU (Section 4.9.15).
(g) VLT software shall be used wherever appropriate.

There is no requirement for closed-loop operation during tracking of a non-sidereal target, but the software shall be written so as not to preclude the addition of a closed-loop mode at a later date.

4.7 High Order Wavefront Sensor

4.7.1 High Order Wavefront Sensor Operation

The high-order wavefront sensor (HOWFS) is not required to operate concurrently with science observations. The telescope can be offset to illuminate directly the sensor with a bright star, limiting the necessary FOV. The sensor Software within the IR Camera package shall allow a suitable star to be selected.

4.7.2 HOWFS Requirements

The requirements for the HOWFS are:

a) 99% probability of finding suitable star within 1° of any telescope position.
b) the required integration time shall be ≤ 180s with a goal of ≤ 60s.
c) at least 22 Zernike or quasi-Zernike coefficients shall be generated, such that the root-sum-square error of all 22 coefficients shall be ≤ 50nm.
d) in the event that a curvature sensing solution is adopted, the implementation shall utilise a 'stepped' filter at one or more 'intermediate' positions of the filter wheel, illuminating one science detector in e.g. J passband. The location of this filter shall be between broadband filters and shall conform to the requirements of Section 4.3.3.7.

4.7.3 HOWFS Detector Controller

The HOWFS detector shall be controlled by ESO compliant detector controllers, e.g. Technical CCD Controller, Next Generation Technical CCD Controller or FIERA. This controller may also control other sensors.

4.7.4 HOWFS Software Functions

Software and hardware on which to run it shall be provided to:

(a) read out the high order wavefront sensor using definable parameters
(b) store the data in the same manner as a science exposure
(c) control the calibration source
(d) analyse the stellar and calibration data generating Zernike and/or quasi-Zernike.
(e) display the raw data
(f) display the wavefront
(h) the software shall run on some of the HOWFS Controller, the Image Analysis LCU and the Image Analysis LCU (Section 4.9.15).
(g) VLT software shall be used wherever appropriate. (It is noted that ESO use Shack Hartmann sensors on the VLT and other telescopes).

4.8 Selection of Stars for Sensors

Selection or confirmation of stars to be used by the sensors shall be performed by the Observation Software (part of the IR Camera work-package).

4.9 Software

4.9.1 Location of Computing Equipment

1. The Instrument LCU, which controls the mechanisms and detector control LCUs shall be mounted on the Camera. The Image Analysis LCU shall be located in the VISTA enclosure, but need not be on the Camera.
2. All workstations shall be located in the Cerro Paranal Control Building. In the Control Room, VISTA will share a console (an open plan work area) with the VST. This console shall accommodate all keyboards, screens and where appropriate, CPUs and storage, necessary for the Telescope Operator to control VISTA and its cameras.
3. A local control workstation will be situated in the office in the Enclosure Basement.

4.9.2 Local Area Networking

1. The IR Camera's computing equipment shall be connected to the Local Area Network via fibre optic.
2. The connection to the IR Camera LCU shall be 10 or 100 Mbps Ethernet.
3. The connections to the workstations, including the IRACE workstation(s), are currently specified in [AD11] and [RD05] to be 155 Mbps ATM, which is, by today's standards, a low performance and expensive solution. The IR Camera shall utilise whatever is selected to replace 155 Mbps for new applications, e.g. Gigabit Ethernet.

4.9.3 Software Hierarchy

The control hierarchy of the principal systems within the IR Camera and related systems is illustrated in Figure 4.2

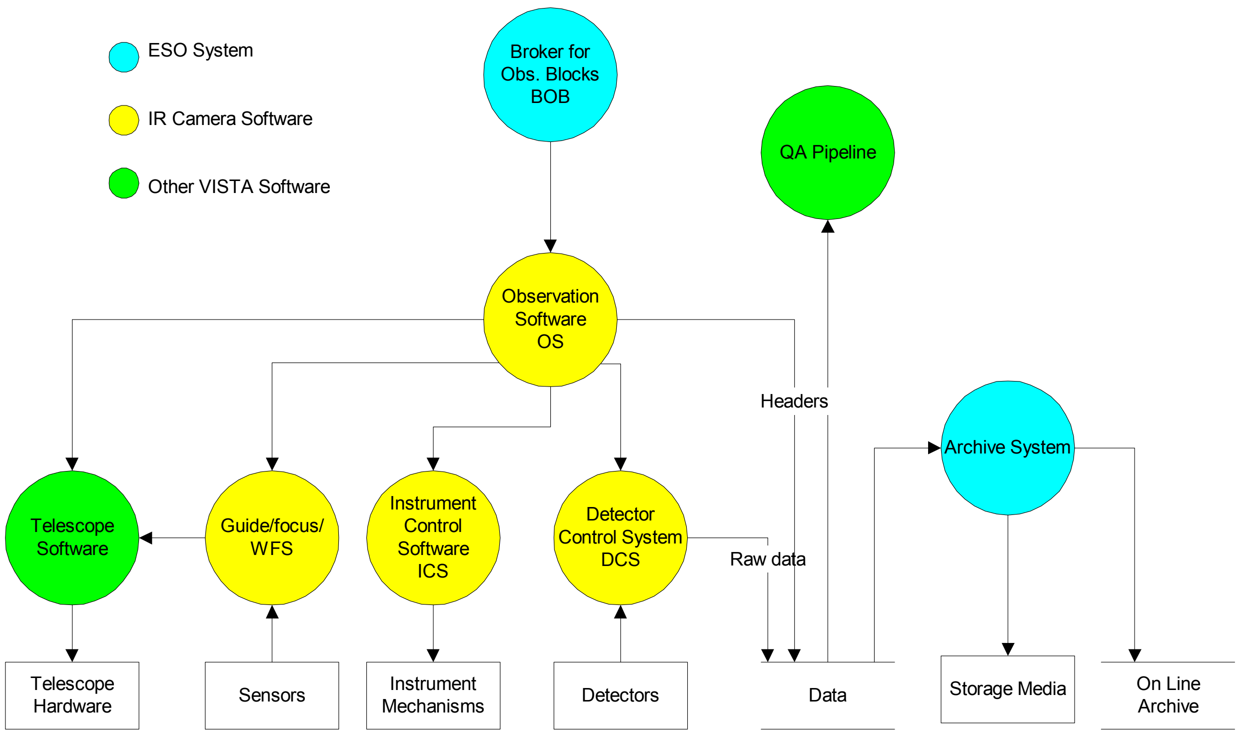

Figure 4.2: Hierarchy of principal software systems within the IR Camera and related systems

4.9.4 General Requirements

1. Software shall conform to ESO programming standards [AD19] and the guidelines for writing application software [AD21]. These documents describe the use of C on LCUs and C++ and Tcl on the Unix workstations. They describe the use of the environment provided by the Common Control Software and the LCU Control Software. Where this environment provides the required functionality, alternatives shall not be used.

2. Existing VLT software shall be reused where appropriate. Examples of such software are:

(vi) Base Instrument Control System [AD24] - provides a template for writing mechanism control software

(vii) Base Observation Software Stub [AD25] - provides a template for writing Observation Software

(viii) Template Instrument Software [AD26] - provides as an example a complete software system for a fictitious instrument

(ix) IR [AD27] and CCD [AD28] detector control software

(x) Telescope Control Software [AD31] - includes reusable software, e.g. guide star selection

(xi) Active Optics module (not formally documented by ESO) - includes software to analyse Shack Hartmann data

3. The software shall fulfil the generic instrumentation software requirements described in the Instrument Software Specification [AD21].

4. The software should fulfil the generic VISTA Instrument Software Requirements [RD02]

4.9.5 Observation Software

4.9.5.1 Requirements

The generic functionality of the Observation Software (OS) is described in [AD21]. This is the highest level module specific to the IR Camera. Its role is to co-ordinate the actions of all the other IR Camera software modules, the TCS and the data handling in response to the information contained in the Observation Blocks that it obtains from the higher level software.

Within the VISTA IR Camera it shall:

(a) obtain Observation Blocks from BOB
(b) configure the instrument hardware via the ICS
(c) control the operation of the telescope via the TCS
(d) control the acquisition of science and calibration data via the IRACE DCS
(e) control the acquisition of guider and wavefront sensor data via their DCSs
(f) control the processing of guider and LOWFS data and their transfer to the TCS
(g) ensure ancillary data is included in the FITS headers
(h) provide a graphical user interface for the operator
(i) generate observation logs

4.9.5.2 Implementation

(a) The OS shall be based on the Base OS Stub [AD25] provided by ESO.
(b) The OS shall run on the Instrument Workstation.

4.9.6 Instrument Control Software

4.9.6.1 Requirements

The generic functionality of the Instrument Control Software is described in [AD21]. Its role is to control the instrument hardware in response to configurations requested by the OS.

Within the VISTA IR Camera it shall:

(a) position the filter wheel
(b) control the Shack Hartman calibration source (if provided)
(c) provide a graphical user interface for maintenance and diagnostics
(d) acquire data from any sensors that may be required
(e) generate an engineering log

4.9.6.2 Implementation

(a) The ICS shall be based on the Base ICS [AD24] provided by ESO.
(b) The ICS shall run on the Instrument LCU and Instrument Workstation.

4.9.7 Science Detector Control System

The Detector Control System shall comprise an IRACE procured from ESO and provided by the VPO to the IR Camera Work Package.

4.9.8 Guide and Wavefront Sensors Detector Control System

The Detector Control System(s) that acquires data from the guide sensor, the two LOWFS sensors (each with two CCDs) and the Shack Hartmann sensors shall be one of:
(xii) ESO TCCD controller
(xiii) ESO Next Generation TCCD Controller
(xiv) FIERA
(xv) IRACE

4.9.9 Guiding

The guiding software requirements are defined in Section 4.5.

4.9.10 Low Order Wavefront Sensing

The LOWFS software requirements are defined in Section 4.6.

4.9.11 High Order Wavefront Sensing

The HOWFS software requirements are defined in Section 0.

4.9.12 Observer Support Software

The requirements for the observer support software are described in [AD21]. This software consists of a number of tools which run separately from the Observation Software and may be used by the observer prior to and during an observing run.

1. The VISTA IR observer support software shall include tools to support the following functions:

    (a) Observation preparation, using information contained in the instrument description and calibration database and test and calibration data supplied with the instrument.
    (b) The preparation and verification of instrument set-up and configuration files, including tools to allow the extraction of instrument set-up files from archived exposures.
    (c) The selection of guide stars and reference objects from standard catalogues.
    (d) Access to standard (and private) procedures to aid the automation of observations.
    (e) Access to archived (standard and private) calibration data.
    (f) Access to an exposure time calculator (see Section 4.9.14.4)

2. Existing ESO observer support tools (such as P2PP and ETC) shall be used wherever possible. New software shall be developed only to provide functionality that is missing from the existing ESO tools.

3. The observer support software shall be able to run stand-alone on any single standard workstation without access to the instrument hardware. Full functionality will be supported in the VLT Control Room and at ESO, Garching. Off-line observation preparation will be supported at remote sites.

4.9.13 Software Maintenance and Verification

4.9.13.1 General

The requirements for the maintenance and verification software are described in [AD21] and the specific software requirements for the maintenance of the VISTA instruments are described in [RD02]. The software falls into two categories described in the following sections.

4.9.13.2 Maintenance Software

Maintenance software provides a set of low-level test facilities designed to verify that instrument components are working within their specification. Maintenance software is geared towards testing the instrument components associated with a single LCU and provides extra tools and utilities over and above those required purely to meet the science requirements.

1. For the VISTA IR Camera Maintenance Software shall:

   (a) provide utilities for self-testing instrument and displaying the results, which involves:
      - checking that all devices present on the LCU bus have connected
      - checking detector controllers are functioning correctly
      - checking all motors and microswitches are working (though for safety reasons no mechanisms should move unless specifically commanded to do so)

   (b) provide utilities for logging instrument faults and alarms

   (c) provide utilities for displaying and logging the health of all instrument components (mechanisms and detectors) and for displaying and logging the cryostat and detector temperatures

   (d) display the current position of all the instrument motors and the state of any microswitches

   (e) provide utilities for logging raw detector data for off-line analysis

   (f) provide engineering functions for moving instrument components directly to particular positions or for manually resetting the detector controllers

   (g) provide utilities for setting instrument configuration and calibration parameters (such as the spatial layout of the detectors and the motor positions at which the filters are centred in the beam)

   (h) provide tools for checking that instrument configuration parameters are valid (such as checking whether a specified filter is installed)

2. Maintenance software shall run on a single instrument LCU and be governed by the same implementation rules as for the rest of the software on that LCU, *viz*:

   (a) ICS maintenance software shall be based on the Base ICS [AD24] provided by ESO.
   (b) Detector controller maintenance software shall be based on the ESO IR [AD27] or CCD [AD28] detector control software.

4.9.13.3 Verification Software

Verification software provides some high level software for carrying out more sophisticated instrument tests or calibration procedures involving the co-ordination of more than one LCU. Verification software utilities operate at the same level as the Observation Software described in Section 4.9.5.

1. For the VISTA IR camera verification software shall:

   (a) provide a utility for calibrating the location of the rotator centre
   (b) provide a utility to calibrate the spatial location of the detectors
   (c) provide a utility to measure detector cross talk
   (d) provide a utility to check for electrical interference with detector readout
   (e) provide a utility to find bad detector pixels
   (f) provide a utility to measure the detector dark current, linearity and saturation.
   (g) provide a utility to check for light leaks, ghost images and detector remnants
   (h) provide automated test procedures for verifying the health and functionality of the entire instrument

2. The verification software shall run on the Instrument Workstation alongside the Observation Software.

4.9.14 Data Flow System

4.9.14.1 Background

The majority of the Data Flow System (DFS) [RD03] associated with the IR Camera is part of a separate project, *viz.* the VISTA Data Flow System. This includes the final data reduction pipeline software that will produce fully calibrated images. This pipeline will also be run at the telescope in order to generate quality control data, but this is not the responsibility of the IR Camera Work Package.

Some DFS components, described below, are the responsibility of this work package (these are formally described in [AD32]).

The following DFS components described in [AD32] will be provided by the VISTA Data Flow System Project, not the IR Camera Work Package:

(a) DFS User Requirements

(b) Calibration Plan

(c) Data Reduction Specifications

(d) Data Reduction Procedures

4.9.14.2 Template Signatures

OB templates shall define the observational modes of the Camera. Parameters used by the templates shall be contained within Templates Signatures, which will be used by the observation preparation tool to P2PP to prepare OBs. Template signatures also contain valid ranges for each instrument parameter.

Some examples of VISTA IR Camera parameters are:

(a) a list of readout modes supported by the science detector controller and wavefront sensor controllers
(b) the windowing and binning modes supported by the science detector controller
(c) the acceptable range of exposure times supported by the science detector controller and wavefront sensor controllers

4.9.14.3 Instrument Description and Calibration Database

The instrument description database contains a full description of all the optical components within an instrument, together with a list of all the valid combinations of those components. This information is used by P2PP to define the available components. In addition, the calibration database contains all the calibration data required to calibrate raw data frames from the instrument.

For the VISTA IR Camera this database shall include:

(a) a list of all the filters belonging to the instrument and a list of the subset of those filters currently installed within the instrument, together with their location. Also a list of filters installed within the wavefront sensors.
(b) the transmission versus wavelength properties of each filter
(c) the quantum efficiency and saturation level of the science detectors as a function of wavelength and readout mode
(d) the linearity of the signal from the science detectors as a function of exposure time (as derived from calibration observations)
(e) the mapping of pixels from each of the science detector chips into "World Co-ordinates" on the sky (as derived from calibration observations)
(f) the location of the rotator axis on the science detector
(g) the location and plate scale of the wavefront sensor detectors
(h) the characteristics of the wavefront sensors (as listed earlier in Sections 4.5, 4.6 and 0)
(i) the acceptable ranges for detector and cryostat temperatures
(j) the location of bad pixels on each detector chip

(k) bias, dark and flat field calibrations
(l) observations of photometric standards
Any other calibration data necessary for the reduction of the data shall be included.

4.9.14.4 Exposure Time Calculator

The VISTA IR Camera shall include an exposure time calculator set-up template and a set of server routines and instrument models, which when combined with the ESO's existing ETC library, will use the instrument description, a description of the observing conditions and the properties of the object to be observed to estimate the signal-to-noise ratio expected as a function of exposure time.

The supplied functions will be incorporated into ESO's existing ETC library and shall therefore be compatible with it, as specified in [AD32].

The exposure time calculator will run on a workstation at ESO, Garching and be accessible via the Internet.

4.9.14.5 Data Interface Dictionary

The Data Interface Dictionary contains a description of all the keywords that will be used to describe instrument information, including both the FITS keywords contained in data headers and any keywords used in instrument set-up files.

Production of the Data Interface Dictionary is the responsibility of the VISTA IR Camera Work Package, but it is recommended that the VISTA Data Flow System project be regularly consulted.

All the keywords used by the VISTA IR camera shall conform to [AD23] and be approved by the VPO and the ESO Data Interface Control Board (DICB).

4.9.14.6 Test and Calibration Data

The deliverables of the VISTA IR Camera Work Package shall include a full set of example data, so the instrument's conformance to the Data Interface Dictionary may be verified. Raw data shall be provided for each of the instrument templates (Section 4.9.14.2), with sufficient metadata to allow the Pipeline to be tested by ESO. A full set of raw calibration data shall also be provided, sufficient to derive all the calibration information contained in the Calibration Database (Section 4.9.14.3).

4.9.15 Computing Hardware

(a) The IR Camera shall include the following computer hardware:

- (i) Instrument Workstation including data storage
- (ii) Instrument LCU (VME crate, CPU and interfaces)
- (iii) IRACE detector controller including IRACE workstation(s)
- (iv) Thermal enclosures
- (v) Guide Workstation

(vi) Detector controller(s) for guide and wavefront sensors
(vii) Image Analysis LCU

(b) It shall exclude [RD03]:

(i) Data Handling Workstation
(ii) Observation Handling Workstation
(iii) Pipeline Workstation
(iv) Archive Storage System
(v) Network equipment to connect the VISTA Enclosure with the Control Building

(c) The IR Camera shall include storage connected to the Instrument Workstation adequate to store 1.4 TB data (maximum data volume from one night).

4.10 Cryostat

4.10.1 Design Pressure

The design pressures shall be set taking into account normal operation (internal vacuum), internal pressure when back-filling with dry nitrogen and accidental overpressure. Requirements apply both to sea level and the altitude of Cerro Paranal.

4.10.2 Pressure Relief Devices

Pressure relief devices shall be provided on the vacuum vessel and LN_2 vessel and shall be sized to prevent the design pressures being exceeded.

4.10.3 Maintenance of Vacuum Pumping

The required vacuum shall be maintained for periods of not less than 12 months, without impacting science observing.

4.10.4 Pumping

Means, e.g. turbo-molecular and a rotary backing pump, shall be provided to achieve the required vacuum for cool-down. It shall be possible to operate this equipment with the camera on or off the telescope and any parts which are not permanently mounted (e.g. roughing or backing pump and flexible connection to the cryostat) shall be capable of being handled safely by one technician. There shall be a gate valve between pump and cryostat.

At least 2 spare ports, minimum size KF40 shall be provided on the vacuum vessel

4.10.5 Prevention of Ice Formation on Optical Surfaces

Means, e.g. cold traps, shall be provided to prevent the absorption of gas onto the optical elements such that the performance, e.g. CIQ and scattering, fails to meet the requirements.

4.10.6 Cooling System

The services for the coolers shall be subject to interface control in accordance with [AD40] and [AD41].

4.10.7 LN_2 vessel filling

Three dedicated ports with KF standard flanges shall be provided which during cool down shall be used for fill tube, venting and LN_2 level gauge.

It shall be assumed that the Camera will be off the telescope for filling with LN_2.

An automated system shall be provided to fill from a storage dewar during cool down.

The design shall be such that at the end of cool down excess LN_2 can be expelled or rapidly evaporated. Valves and a pump shall be provided to evacuate and isolate the LN_2 vessel after cool down.

4.10.8 Thermal Insulation

The thermal performance of the instrument shall be maintained after repeated removal and reinstallation.

If utilised, MLI blankets shall be designed such that they can be easily and reliably installed and removed by not more than two technicians.

4.10.9 Warm-up/Bake-out Heaters

Automated heaters shall be provided on the cold structure to enable a controlled warm up of the instrument and for controlled accelerated outgassing.

4.10.10 Instrumentation

4.10.10.1 Vacuum

Gauges covering the full operating range shall be provided.

4.10.10.2 LN_2 Level

A gauge(s) shall be provided for monitoring the level of LN_2 during the filling operation. It shall be possible to exchange this gauge without any dismantling of the cryostat.

4.10.10.3 Temperature

Monitoring devices shall be provided as a minimum at the following locations:
a) Science detectors
b) WFS detectors
c) Optical bench/LN_2 vessel
d) Lens barrel

e) Cold baffle entry
f) Cold baffle exit
g) Window bezel

4.11 Instrument Handling

4.11.1 General

The IR Camera will be handled by means of a specialised handling tool, which is part of the supply of the work package. The handling tool will be used in conjunction with the enclosure crane for moving the Instrument within the enclosure and for mounting to and dismounting from the Telescope. The Telescope is orientated Horizon pointing for the installation and removal operations, the interface with the facility handling equipment is detailed in [AD63] and the interface between the instrument and Cassegrain rotator in [AD62].

The details of the Interface between the handling tool and the Instrument and of the procedures for ensuring accurate and repeatable mounting of the Instrument will be developed in conjunction with the detail mechanical design of the instrument cryostat and the Telescope Cassegrain rotator.

4.11.2 Handling Equipment

The Work Package shall provide the following handling equipment and special tooling:

- The Camera Handling Tool
- Custom or special handling tools not obtainable through normal purchasing practice
- Fixtures necessary to secure the Instrument and its internal components during transportation

4.11.3 Service and Test Equipment

The Work Package shall provide a storage stand that will allow for testing of the Camera whilst it is off the Telescope. The stand will be mobile and normally located in the Instrument preparation area situated in the basement of the enclosure. The stand will be manoeuvred into position beneath the hatch door in the Azimuth floor, the Camera will be either lifted from or loaded onto the stand with the Camera secured to the handling tool and hanging on the enclosure crane with its Z-axis in the horizontal position.

The storage stand shall be designed with the following requirements:

- Shock absorbing devices to absorb minor shocks when the Camera is lowered onto it
- Attachments to secure the Camera
- Anchoring points at which the stand can be secured
- Access to the Camera for all maintenance operations and servicing
- Provision for connecting all electrical and cooling services
- To be manoeuvrable with the Camera in situ within the confines of the enclosure
- Covers for the protection of the Camera.

5 REQUIREMENTS FOR ANALYSES

5.1 Safety

Hazard analyses will be performed following best practice in accordance with AD13. The deliverable will be DRD 200 as defined in [AD44].

5.2 Technical Risk

An analysis of technical risk, subject to VPO approval shall be carried out.

A work package risk register shall be maintained.

The results of the approved risk analysis shall be used to determine which load cases, additional to those which are predictable and arise from the functional specification or from statutory or ESO requirements are required for verification of the structural integrity.

5.3 Structural Integrity

5.3.1 Considered effects

a) Atmospheric and internal pressure loads
b) Gravity at 0°, 45° and 90° altitude angle
c) Thermal effects at operational temperatures
d) Non-equilibrium thermal effects during Cool-down and Warm-up
e) Thermal effects arising from cryogenic failure (rapid warm up)
f) Earthquake OBE
g) Earthquake MLE
h) Slewing decelerations due to telescope emergency braking and end stops of $60°/s^2$ (altitude axis) and $120°/s^2$ (rotator axis)
i) Survival wind speed
j) Handling
k) Transport

5.3.2 Load cases

5.3.2.1 Operational Loading

(a)
(b)
(c)
(a)+(b)+(c)
(a)+(b)+(c)+(d)
(j)

5.3.2.2 Short Term Accidental Loading

(a)+(b)+(c)+(e)
(a)+(b)+(c)+(f)
(a)+(b)+(c)+(h)
(k)

5.3.2.3 Survival Loading

(a)+(b)+(c)+(g)
(a)+(b)+(c)+(i)
(j)+(f)

5.3.3 Thermal

For input to structural analysis the following shall be considered
a) Cryogenic failure modes
b) Transient conditions during warm-up and cool-down

5.3.4 Fluid flow

Pressure relief devices sizing.

5.4 Performance

5.4.1 Optical

Stray-light and ghosting analyses, etc. shall be performed to demonstrate compliance with the requirements in Section 3.18. These shall include a simplified model of the dome, telescope structure, M2 baffle, etc. For these purposes the following assumptions can be incorporated:

(a) dome walls shall be assumed to be white paint for scattering purposes and 100% emissive for thermal purposes.
(b) The dome floor shall be assumed to be dark grey paint.
(c) The M2 baffle shall be assumed gold-coated (2% emissivity).
(d) It shall be assumed that the telescope mirrors, M2 baffle and exterior camera window shall be dust free in complying with the requirements.

The analysis shall also estimate the effects of dust on the various surfaces though no requirements are specified.

5.4.2 Flexure

5.4.2.1 Considered Effects

a) Atmospheric and internal pressure loads
b) Gravity at 20°, 50° and 88° altitude angle
c) Operational thermal loads

5.4.2.2 Load Cases

(a)
(b)
(c)
(a)+(b)+(c)

5.4.3 Thermal

1. Thermal analysis shall demonstrate that the following requirements are met:
    a) Steady state temperature
    b) Detector temperature stability
    c) Cool down and warm up rates
    d) Window external temperature, condensation and icing

2. Thermal analysis shall be used as an input to:
    a) Cooler specification
    b) Pre-cool system specification
    c) Temperature sensor quantity and location

5.5 *Stress Verification Criteria and Limits*

The stress criteria that shall be verified and the corresponding allowable limits are given in **Table 5.1**. Fatigue limit is defined as the allowable stress for $>10^6$ load applications before failure.

Cases	Criteria	Allowable Stress (minimum of values to be used unless otherwise stated)
Operational loading	Any failure.	Manufacturers recommendation Ultimate tensile strength/4 0.2% Proof Stress/1.5 Fatigue limit/2 [AD55] where applicable(Note 1)
Short term accidental loading and Survival loading	Failure leading to unacceptable or undesirable hazard.	Manufacturer's recommendation Ultimate tensile strength/4 0.2% Proof Stress/1.5 [AD55] where applicable(Note 1)
	Failure leading to acceptable hazard.	Manufacturer's recommendation Ultimate tensile strength/2.5 0.2% Proof Stress/1.2 [AD55] where applicable(Note 1)

Table 5.1: Criteria and Limits for Stress Analysis

[1]In the case of the vacuum vessel and the LN_2 vessel design stresses for the materials of construction shall be taken from [AD55].

For fabricated structures the values of allowable stress shall take the effects of welding into account.

5.6 *Acceptable Earthquake Hazards*

Acceptable hazards in the event of an earthquake (load combinations f and g of section 5.3.1 are defined in [AD43].

Earthquake Type	Acceptable Hazard	Not Acceptable Hazard
OBE	None	Minor system damage Major system damage System Unrecoverable Severe injury or death
MLE	Minor system damage Major system damage	System Unrecoverable Severe injury or death

Table 5.2: Acceptable Earthquake Hazards

5.7 Modelling

5.7.1 Structural

All Finite Element analyses necessary for the verification of the design and the performance of the camera shall be performed with a recognised numerical code to be approved by the VPO. The structural model shall be sufficiently detailed to provide an accurate description of the quantities under study (stiffness, stresses, natural modes, displacement, etc.).

The accuracy level that is expected for the verification of compliance with this specification is:

Mass accuracy	5 % of full mass
Inertia accuracy	10 % of full inertia
Centre of mass position	5 mm
Accuracy of natural frequency	10 %
Accuracy of static analysis	5 %

The deliverable shall be an analysis set DRD 22 as defined in [AD44].

5.7.1.1 Seismic Analysis

Seismic analysis shall be in accordance with [AD07].

The value of parameter a (ratio of peak base acceleration to gravity) to be used is (TBC following the telescope workpackage PDR):

OBE 1.8 g

MLE 2.4 g

5.7.2 Optical

Optical modelling shall be completed using established design software as agreed by VPO. Ray tracing shall incorporate the M1 and M2 optical prescriptions defined in [AD36].

5.7.3 Thermal

Lumped parameter models shall be sufficient except where the risk analysis requires otherwise. The models shall include:

a) temperature dependent variation of material properties

b) thermal contact resistances

The deliverable shall be an analysis set DRD 22 as defined in [AD44].

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